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ABSTRACT

The purpose of this report is to present and prioritize the major environmental issues associated with the further development of biomass production and biomass conversion systems. To provide a background for this environmental analysis, the basic concepts of the technology are reviewed, as are resource requirements. The potential effects of this technology on the full range of environmental concerns are then discussed in terms of both their relative significance and possible solutions. Although the further development of biomass production and conversion will contribute to environmental problems common to modern cultivation practices or energy conversion technologies, only those impacts unique to the solar portion of the technology are discussed in depth here. Finally, an environmental work plan is presented, listing research and development proposals and a NEPA work plan which might help clarify and/or alleviate specific environmental problems. (Author/MR)

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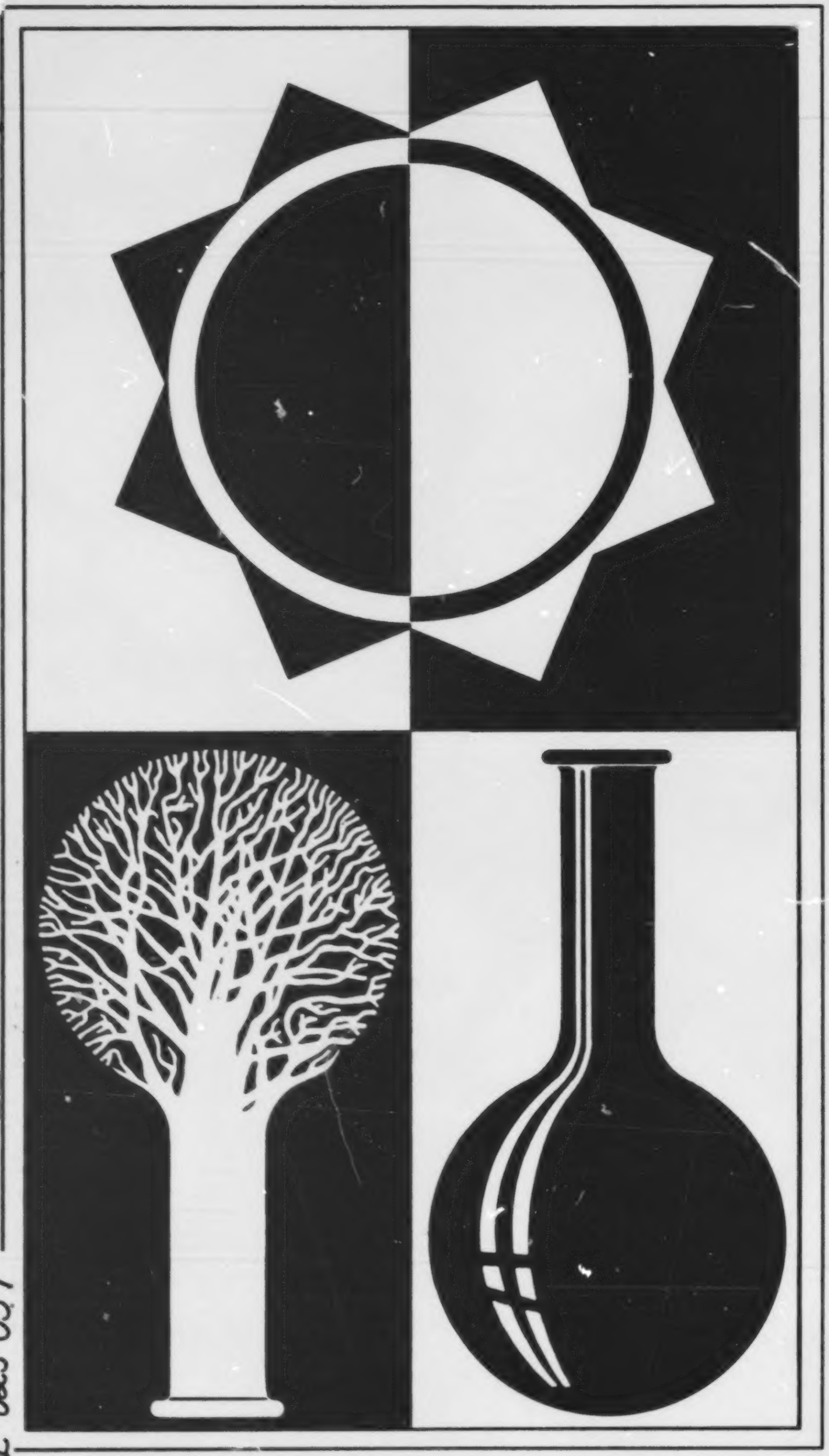
SOLAR PROGRAM ASSESSMENT: Environmental Factors



Fuels from Biomass

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SECTION I

INTRODUCTION AND ENVIRONMENTAL SUMMARY

A. Organization and Intent of Report

The purpose of this report is to present and prioritize the major environmental issues associated with the further development of biomass production and biomass conversion systems. Biomass production/conversion is one of the eight Federally-funded solar technologies. To provide a background for this environmental analysis, the basic concepts of the technology are reviewed, as are resource requirements. The potential effects of this technology on the full range of environmental concerns (i.e., air and water quality, biosystems, safety, social/institutional structures, etc.) are then discussed in terms of both their relative significance and possible solutions. Although the further development of biomass production and conversion will contribute to environmental problems common to modern cultivation practices or energy conversion technologies (e.g., coal conversion, boiler combustion, etc.), only those impacts unique to the solar portion of the technology will be discussed in depth. Finally, an environmental work plan is presented, listing research and development proposals and a NEPA* work plan which might help clarify and/or alleviate specific environmental problems.

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* For a discussion of NEPA documents, see Section IV.

B. Salient Environmental and Safety Issues

1. Land Resource Requirements For Terrestrial Biomass Production

The production of terrestrial biomass as an energy source requires substantial acreage. Two options are available in plantation design: 1) the production of biomass as the sole activity of the plantation, or 2) the production of biomass in support of an onsite direct conversion facility, such as a wood burning power plant that generates electricity.

The first design requires enough land to produce an economically viable yield, or approximately 250,000 dry tons (227,000 metric tons) annually. Such requirements would be in the range of 18.75 to 47 square miles (49 to 122 Km^2) of forest growth per plantation. Total acreage required to supply one percent of the present energy needs of the U.S. would run between 1.5 and 4.5 million acres (0.6 and 1.8 million hectares).

The second design offers a more concrete example of land use. For example, supplying a "baseload" 100-MW powerplant with wood would require a plantation area of 51 square miles (132 Km^2) total, of which 10 square miles (25.9 Km^2) would be harvested annually on a 5-year tree rotation scheme.

Unused land which meets these acreage requirements is available; however, patterns of ownership, soil quality, water availability, and competition with food and fiber production affect its use for biomass fuel production.

2. Gaseous, Liquid, and Solid Residuals From Thermochemical Biomass Conversion

Thermochemical biomass conversion can produce gases, tars and oils, unconverted residue (char), and ash, depending on the particular conversion process employed. Pollutants associated with these products can affect air and water quality as well as land use. Combustion of these products also can affect the environment through combustion-related pollutants such as gaseous emissions and ash.

Thermochemical reactions generate sulfur-containing gases (H_2S, COS, CS_2, SO_x) and nitrogen-containing gases (HCN, NO_x, NH_3). Because of the nature of the pollutants and the scale on which they can be generated during thermochemical reactions, sulfur-containing compounds - primarily H_2S - offer the most concern as potential air pollutants. For these reasons, similar coal-based gasification procedures employ systems to remove or control their emission into the atmosphere. However, biomass contains an inherently low sulfur content, and the production of sulfur-derived pollutants occurs at a much lower level than during coal gasification. Nevertheless, uncontrolled venting of these raw off-gases may cause local air standard violations and possible odor problems due to H_2S concentrations. However, the potential concerns may be eliminated by flaring the gas -- converting H_2S into less harmful quantities of SO_2 and water -- or chemically treating the gas to remove H_2S.

Thermochemical processes will also generate ash, which is present in the nonvolatile portion of the biomass. This material does not undergo conversion and must be disposed of. Disposal may include land spreading of the ash as a fertilizer, use in construction materials (i.e., cement), or landfilling (which would affect land use). However, as with sulfur content, biomass ash contents are quite low compared to coal; consequently, land requirements for biomass ash disposal are not as great. Furthermore, because of the nutrient value of the ash, it is likely that the ash will be recycled to biomass plantations.

Water quality can be affected by gaseous condensates, low-molecular weight oils, phenols, leachates from char and ash residues, and scrubber solutions, all of which may enter water bodies through discharge from disposal ponds and percolation to subsurface waters. These impacts may be more acute if water is used in the reaction, as proposed with some processes. Adverse effects on water quality may be prevented by channeling wastes to evaporation ponds, adequate in size so as not to require discharge into waterways. If required, chemical treatment of such ponds can be employed to reduce their pollution potential.

Because sulfur and ash contents are inherently low in biomass, the secondary fuels produced from biomass (via thermochemical conversion) also will have low sulfur and ash contents. Thus, sulfur-containing emissions from combustion of biomass secondary fuels will be low, as will the volume of ash for disposal.

3. Impacts Related to Combustion of Biomass (Wood)

Combustion of fuel in utility boilers releases residuals to the air and produces solid waste that can impact the environment. Fuel storage, fuel handling, and ash disposal can also affect the surrounding environment. Air pollutants of concern are those that are normally generated during fossil-fuel combustion. They include particulates, nitrogen oxides, and carbon monoxide. Water pollutants of concern are leachates from storage piles or ash deposits, although in the latter case potential water quality impacts will be quite minor if the ash is recycled to plantation sites.

The major air pollutant of concern from wood boilers is particulate matter, although other air pollutants, particularly carbon monoxide, may be emitted in significant amounts under poor operating conditions. Such conditions are not unique to wood combustion: they may occur also during combustion of fossil fuels. The overall emissions may be affected by selection of wood, the type of particulate control device, and furnace design and operating conditions. Manipulation of these variables to achieve optimal conditions can reduce air pollutant emissions. In addition, sulfur oxide emissions from wood combustion are inherently low in comparison to those of coal or oil combustion, due to the low sulfur content of wood.

Water pollutants originating from the storage of fuel (wood) and the disposal of ash may affect water quality, though to a much smaller degree than encountered in coal use which also requires fuel storage and ash disposal. Similar to sulfur content, the ash content of biomass is quite small, and the nature of wood ash compared to coal ash is one of significantly less potential harm to the environment (through trace elements present in the ash). However, concentrated disposal of ash in areas where discharge into waterways occurs may thus affect the quality of local receiving watersheds. Fuel-storage water quality impacts result from rain runoff from storage piles. The structure of wood prevents water from leaching the majority of potential pollutants from within the wood, and substantial leaching thus does not occur. Nevertheless, under poorly managed conditions, detrimental runoff from storage piles -- in particular, those which contain wood chips -- can occur, possibly affecting local water quality through addition of suspended solids and organic loads to the water.

Generally, utility combustion of biomass will generate most pollutants encountered with fossil-fueled utilities. However, pollutants related to sulfur and ash contents will be low relative to coal use.

4. Depletion of Soil Organic Content Due to Residue Removal

Recovery of agricultural residues and/or total harvesting schemes serve to reduce the beneficial natural replenishment

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of organic residue content in the soil. Environmental impacts distinct to biomass production are associated with removal of residues normally left in the field as opposed to those normally removed for disposal or sale.

Crop residues remaining on open farmland play a major role in shielding soil from wind action, preserving moisture content, and contributing organic content to the soil. Their removal will increase windblown dust and serve to deplete the organic soil content which enhances the internal binding of the soil. Fugitive dust potential would be further increased if total residue removal was employed and continued for several growing seasons, progressively reducing the binding organic content of the soil.

Water impacts will result from possible increased erosion and resultant sediment loading of local waterways. This source of pollution also results from mechanisms that contribute to wind erosion.

Mitigation of potential fugitive dust and water erosion would involve those activities that shield the soil and/or preserve its organic content. Partial removal of residue quantities is one possibility, though the percent that can be safely removed has not been determined. Principally, the use of "no-till" farming in conjunction with total crop removal schemes would cause less fugitive dust than under till-farming conditions. No-till farming leaves the soil undisturbed for several seasons by not employing discing for seedbed preparation. No-till methods preserve root structure, providing aeration and organic content to the soil, thus aiding its binding ability.

It should be noted that, as opposed to crop residue removal, forest residue removal may have beneficial impacts. Forest residues created by logging operations can clog streams and increase the occurrence and intensity of forest fires. Removal of these residues mitigates such impacts and contributes to better forest management.

5. Disposal of Waste Sludge from Anaerobic Digestion

Anaerobic digestion, a bioconversion process, is primarily a means for converting animal residue to usable fuel, although it can be applied to other organic residues as well. Anaerobic digestion occurs in an aqueous medium and, consequently, water quality impacts are possible. The source of these impacts is waste sludge (unconverted organics and residual inorganics) remaining from the digestion process.

Commonly, waste sludge from small digesters is disposed of in an evaporation lagoon; for large digesters, application of the sludge as fertilizer may be employed. If disposed of in a holding pond, infiltration of sludge wastewater to groundwater should be prevented. In addition, discharge from the pond into waterways, if it occurs, must be channeled into waterways with a sufficient flow rate to dilute pollutants. If the sludge is used as a fertilizer, it should not be applied to one area for an extended period. Such application may cause an adverse buildup of salts and heavy metals in the soil, because digester wastewater or holding pond effluent may contain salt loads comparable to those present over much larger acreages than those to which the wastewater is applied.

Raw manure is sometimes disposed of in oxidation ponds open to the atmosphere. By comparison, digester sludge will have less pollution potential than raw manure, though the potential is not eliminated by anaerobic treatment.

SECTION II

BIOMASS PRODUCTION AND CONVERSION TECHNOLOGIES

A. Introduction

As a solar technology, biomass production and conversion is concerned principally with the photosynthetic species of terrestrial and marine plant life. Within these organisms, energy from the sun is utilized to transform elements of the air, water, and soil into complex organic compounds, chiefly carbohydrates. Essentially, these compounds contain a portion of the solar energy vital to their synthesis. Accordingly, biomass production attempts to optimize photosynthesis while biomass conversion attempts to exploit the energy fixed within the cellular structure of plant matter.

The overall photosynthetic process, in its simplest form, is a series of oxidation-reduction reactions of which the beginning and end products may be represented in the following equation:

$$6CO + 6H_2O \xrightarrow{\text{light}} (CH_2O)_6 + 6O_2$$

Carbon dioxide   Carbohydrate

The major source of energy within the plant is the abundant and ubiquitous carbohydrate, cellulose, which is a primary product of photosynthesis.* Unfortunately, photosynthesis is a limited process and theoretical yields can only be approached.

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* The heat content of most dry plant mass ranges from 7,500 to 8,500 Btu per pound. This compares to 12,500 Btu/pound for coal and 21,000 Btu/pound for gasoline.

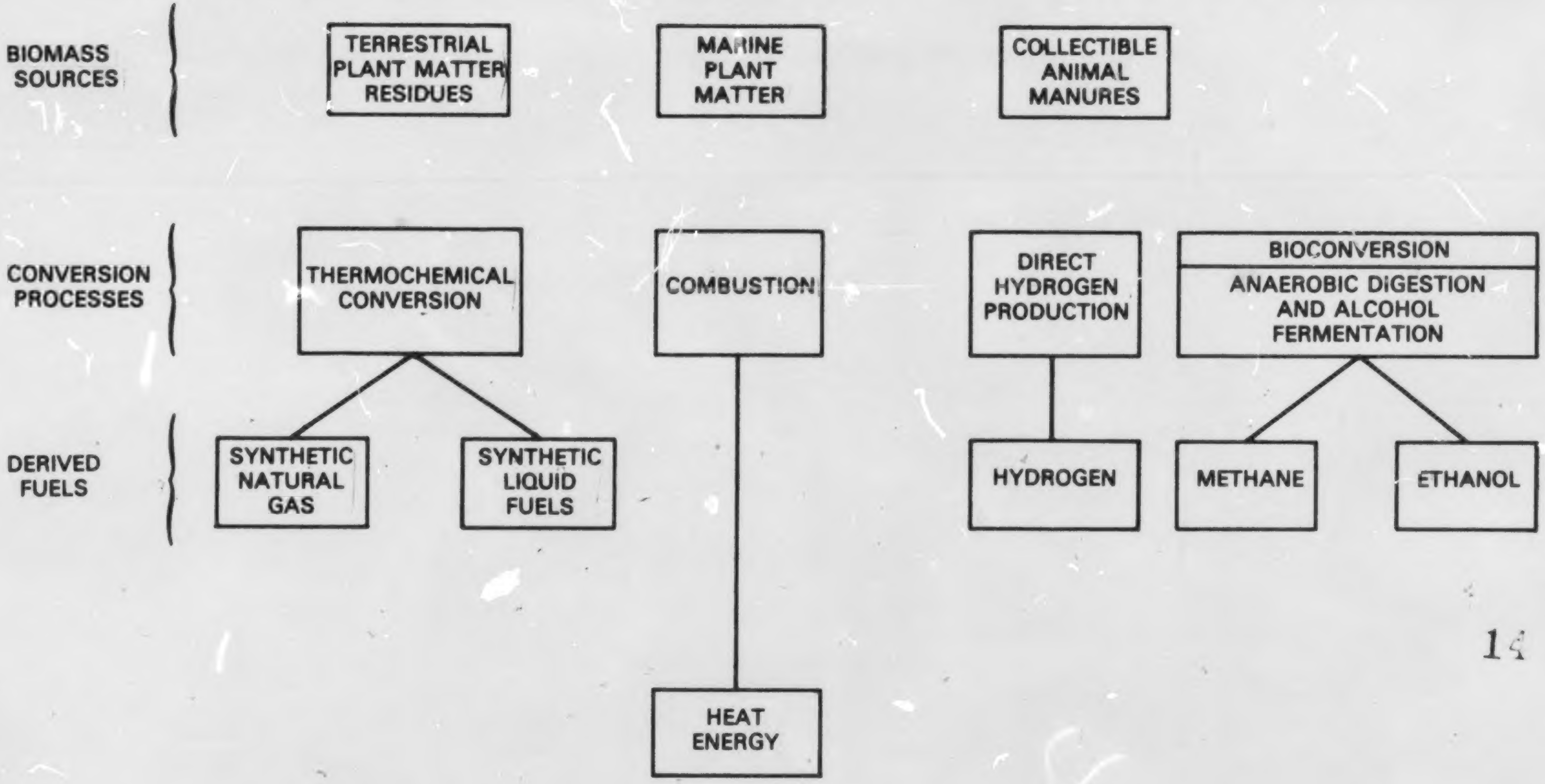
For example, calculated maxima have indicated a utilization efficiency of 5.2 percent of total incident solar radiation and 12 percent of "photosynthetically active radiation" (PAR). However, actual field efficiencies generally range between 1 and 3 percent PAR.[1] The greatest drawback for biomass conversion is thus the low efficiency of conversion.

Nevertheless, biomass is attractive as a fuel source because it is renewable, unlike current major energy sources. In the Energy Research and Development Administration (ERDA) "Fuels From Biomass" program, two principal areas are considered. The first encompasses sources of biomass, such as terrestrial and marine growth and the collectible animal manures (which contain large amounts of undigested cellulose). This area is discussed above. Section II-C discusses the second area of interest: biomass conversion. Here processes are considered which convert biomass into usable energy forms. The major processes are thermochemical conversion, bioconversion, combustion, and direct hydrogen production.

Figure II-1 shows the interrelationships between sources of biomass, conversion processes, and secondary fuels. Interconnecting lines are not drawn between sources and conversion technologies because all biomass, basically, is applicable to any one process. However, some forms of biomass are best suited to certain technologies and these will be mentioned when appropriate.

Biomass conversion encompasses both old and new technologies. The old include combustion and microbial fermentation (bioconversion). The new include thermochemical conversion and direct hydrogen production. The integration between conversion technologies, biomass sources, and final uses are often tenuously formulated. Biomass conversion and production, as an integrated design, is an infant concept. For these reasons, this study focuses on individual areas of investigation, reflecting the current program state of the art.

FIGURE II-1
THE FUELS FROM BIOMASS PROGRAM


BIOMASS SOURCES
TERRESTRIAL PLANT MATTER RESIDUES
MARINE PLANT MATTER
COLLECTIBLE ANIMAL MANURES
CONVERSION PROCESSES
THERMOCHEMICAL CONVERSION
COMBUSTION
DIRECT HYDROGEN PRODUCTION
BIOCONVERSION
ANAEROBIC DIGESTION AND ALCOHOL FERMENTATION
DERIVED FUELS
SYNTHETIC NATURAL GAS
SYNTHETIC LIQUID FUELS
HYDROGEN
METHANE
ETHANOL
HEAT ENERGY

SOURCE: EEA, Inc.

B. Sources of Biomass

1. Terrestrial Biomass Growth

The cultivation of biomass is a practice well established throughout history; long ago it was realized that controlled farming conditions could achieve greater yields than encountered under natural, uncontrolled conditions. During recent decades intensive cultivation practices have resulted in harvests unattainable in the earlier part of this century. Since 1934, farm productivity per acre has tripled, and the output per man-hour has increased by a factor of seven.[2] Modern silvicultural management practices have also increased yields in commercial forest growth, although they have not been able to achieve full yields in some areas. It is in the light of now-common statistics on record agricultural and timber harvests that consideration of biomass as an energy source has taken place.

The concept of a "biomass plantation" follows from this view. Rather than serving as a food or fiber resource, biomass would be grown expressly for its energy content. The goal would be to produce the greatest amount of biomass (measured in usable Btu's) per unit time and space at the lowest possible cost and with a minimum energy expenditure.

The biomass plantation, or energy farm, is a concept incipient in its application. Limitations of its use include the relative low efficiency of the photosynthetic process, the limited availability of productive land, and the inevitable competition with food and fiber cultivators for farming resources (water, land, fertilizers). The principal advantage over other energy sources is that biomass is essentially renewable. Thus, potential applications of biomass have been focused basically in two areas: (1)

high yield crops, rich in energy content, and (2) the use of rapid growth, short rotation tree species.

Within the first category there are many species of high yield crops from which to choose. Unfortunately, requirements of sunlight, climate, soil, and water tend to limit the cultivation of many such plants to areas already used for food production. Ideally, biomass crops and trees would be grown in areas where such competition does not take place (i.e., on marginal lands). However, it is worthwhile to examine such high growth species, since they demonstrate several desirable characteristics of a biomass fuel. Some of those being studied are mentioned herein.1/3/4/

- Sugarcane is predominately grown (in the continental U.S.) in Texas, Louisiana, and Florida. It is a high yield crop capable of sprouting from its chopped stubble (i.e., it is a "ratoon" crop). Yields of cane in Florida under the ratoon system (5 years - 4 harvests) average approximately 47.3 tons/acre (105 metric tons/hectare) wet weight. This corresponds to a dry weight value of 13 tons/acre (29 metric tons/hectare). It has been suggested that if the ratoon system were abandoned and reed cane were planted each year, approximately 30 tons/acre (65 metric tons/hectare) of dry cane would be harvested each crop.
- Sugarbeets are capable of yielding 25 tons per acre-year (56 metric tons/hectare-year), but high yields require an ability to control water availability and nitrogen supply. One ton of sugarbeets requires approximately 10 lbs of nitrogen (4.9 Kg/metric ton), depending on location. Although there is more land in the U.S. suitable for sugarbeet production than for sugarcane, sugarbeets are usually planted only once every 4 years because of disease problems.

- Sweet sorghum is another plant capable of ratoon crops. Since yields of 20 to 50 wet tons per acre (45 to 112 metric tons/hectare) in Texas can be produced during a 140-day growing season, 2 crops per year are possible in conducive locales. Sweet sorghum also may be grown over a much wider geographical range than sugarcane.
- Kenaf is an annual plant reproduced by seed only. It has a fibrous nature (75% cellulose) and, as a potential pulp crop, is several times more productive than the traditional pulpwood trees. Yields of 20 tons (dry) per acre (45 metric tons/hectare) have been reported in Florida. Kenaf requires wet locales and fertilizer for optimum growth; per pound of dry Kenaf, about 0.01 lb N, 0.005 lb P_2O_5, and 0.01 lb K are required.

The cultivation of crops for fuel has the advantage of obtaining high yields over relatively short time spans (6 months to a year). In addition, the sugar crops (sugarcane, sugarbeets) are capable of providing starting materials - simple sugars - from which ethanol may be derived (see section II-C-2). However, crops have high moisture contents, require fertilization, and present storage problems as many have a tendency to spoil. Because of certain limitations inherent in biomass crops, the utilization of trees as an energy source may have certain advantages. Trees are hardy plants able to withstand a wide range of climates and locales. They require less intense soil preparation than other crops, and they will not spoil in the field. Furthermore, most hardwood species will coppice (grow from shoots after cutting), which gives them the characteristic of a perennial.

The eucalyptus tree has been cited frequently as a good plantation candidate. It is a pest-resistent tree, high in cellulose content, and is capable of sprouting profusely from a stump. Moreover, it is remarkably adaptive to different locations. Short-rotation schemes for the eucalyptus usually require a schedule of 6 to 7 years before cutting.[5/] The pulp industry perhaps gives the best silvicultural model for a biomass plantation. It employs short-rotation hardwoods capable of being harvested on a 3- to 5-year schedule.[1/] This system entails the harvesting of relatively young wood and using the entire aboveground portion of the tree (bark, branches, and bole). In an energy plantation design, these trees may be cultivated as row crops and harvested by conventional silage crop harvesting equipment.

Besides eucalyptus, potential tree species for a silvicultural (forest cultivation) energy plantation include the following:[5/]

- sycamore (Georgia, Mississippi);
- red alder (Washington, British Columbia; 5-year rotation);
- cotton (North Dakota);
- hybrid poplars (New England, Minnesota; 7-year rotation); and
- green ash (Nebraska; 8-year rotation).

The yields from such species vary between 5 to 12 dry tons per acre-year (11 to 27 metric tons/hectare); under careful management, expectations would be in the range of 16-20 dry tons per acre-year (36 to 45 metric tons/hectare).[5/] By comparison, expected agricultural yields within the framework of an energy plantation are given at 30 dry tons per acre-year (67 metric tons/hectare).[1/]

Whether utilizing crops or trees, the basic design and land requirements of an energy plantation are similar. As an agricultural system, the employment of "no-till" farming and other modifications such as the harvest of roots and crowns and the use of understory or shade-loving crops (grown beneath the canopies of primary biomass crops) have been suggested. For managed forest growth, practices similar to those used by the pulp industry likely would be employed. In both cases, facilities for combustion or derivation of synthetic fuels would probably be located on energy plantations in strategic locations, such as the center. This would couple energy production with conversion, minimizing transportation of the biomass to the conversion facilities and would probably aid in reducing total (biomass production and conversion) land requirements.

Many immense tracts of land are needed. From an economic perspective, an energy plantation would require enough land to generate a sustained yield of approximately 250,000 dry tons (227,000 metric tons) annually.[5/] Depending on land, climate, and crops grown, such land requirements would be in the range of 12,000 to 30,000 acres (4,800 to 12,100 hectares). In 1974, the gross energy requirement of the U.S. was approximately 7.3 x 10^{16} Btu (1.8 x 10^{16} Kcal).[6/] If terrestrial biomass were to supply one percent of this need, approximately 4.5 million acres (1.8 million hectares) would be needed for total forest growth, or 1.5 million acres (0.6 million hectares) would be needed for high-yield crop growth.*

An ongoing ERDA study has recently estimated from site surveys that over 3 million acres (1.2 million hectares) are available (unused and in adequately-sized tracts) for use as biomass silvicultural plantations.[5/] From the standpoint of ease of conversion to cropland, a 1975 USDA publication reports that the major available farm acreages are in the Northern and Southern Plains [almost 58 million acres (24 million hectares) of pasture and range], the Mountain States [15 million acres (6 million hectares)], and the Corn Belt [about 12 million acres (5 million hectares)].7/ This acreage is not presently in cropland use; however, of these 85 million acres (34.4 million hectares) 99 percent have problems of erosion, wetness, soil limitations, and/or climatic hindrances that must be overcome before cultivation can take place economically. Moreover, for much of this land strong physical, economic, and institutional factors have kept it out of cropland use. These include size of land tracts, patterns of ownership, and ease and scale of development.7/

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* Based on a biomass heating content of 8,000 Btu/dry lb (4,440 Kcal/Kg) and average yields of 9.5 dry tons per acre-year (21.3 metric tons/hectare-year) for crop growth and 30 dry tons per acre-year (67 metric tons/hectare year) for forest growth.

Because an individual biomass plantation will require a large land area, the ERDA estimate of 3 million acres (1 million hectares) which includes only large, unused, available land tracts, probably represents a more practical account of available land. However, institutional and economic factors will limit, to a degree, how much of this land can be used for biomass "energy" production in the near term.

2. Marine Biomass Production

The oceans cover some 70 percent of the earth's surface and receive over half its natural insolation. In this respect, the oceans contain approximately 5 to 10 times more potentially productive surface than land.8/ Yet, in contrast to exploitation of marine animal life, farming of marine plant biomass has never been realized to any appreciable extent. However, the increased demand for food and energy has led to serious considerations regarding the farming of marine biomass. This concept is principally represented in the Ocean Farm Project, a three-phase effort designed

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to establish, by 1985, an operating "demonstration" marine farm system contained in over 100,000 acres (40,000 hectares) of open ocean.[9/]

The marine farm concept is based on the use of attached seaweeds, which represent the greatest amount of collectible plant matter in the ocean. These seaweeds have been used for industrial purposes in the past because they could be gathered from their naturally occurring beds. The collection of the larger kelp species for their components of iodine, potash, and algin represent the major commercial efforts in this area. On the Pacific Coast, the three kelps which occur in sufficient quantity to be economically harvested are *Macrocystis*, *Nerocystis*, and *Alaria fistulose*.[10/] In particular, a key potential candidate for marine farming is *Macrocystis pyrifera*, or Giant California Kelp, which is a rapidly growing plant exhibiting a high photosynthetic efficiency of about 2 percent. It is also one of the largest of the brown algae, growing up to 150 feet (46 m) long.[11/] A diagram of a young plant is shown in Figure II-2.

In the Marine Farm (MF) concept, the holdfasts of *Macrocystis pyrifera* are attached onto polypropylene lines forming a grid network suspended 50 to 100 feet (15 to 31 m) below the ocean surface.[9/] Figure II-3 depicts a typical raft structure which was actually employed at an experimental MF site.

Initially, the kelp plants are brought by divers from their natural beds to the grid structure, where they are placed 9 to 12 inches (0.2 to 0.3 m) apart. This growth density is expected to yield 340 tons of wet harvest per acre-year (760 metric tons/ hectare-year). This corresponds to approximately 34 tons of dry harvest per acre-year (76 metric tons/ hectare-year) at an energy

FIGURE II-2
DIAGRAM OF A YOUNG ADULT MACROCYSTIS PLANT
(AT A DEPTH OF ABOUT 30 FEET)

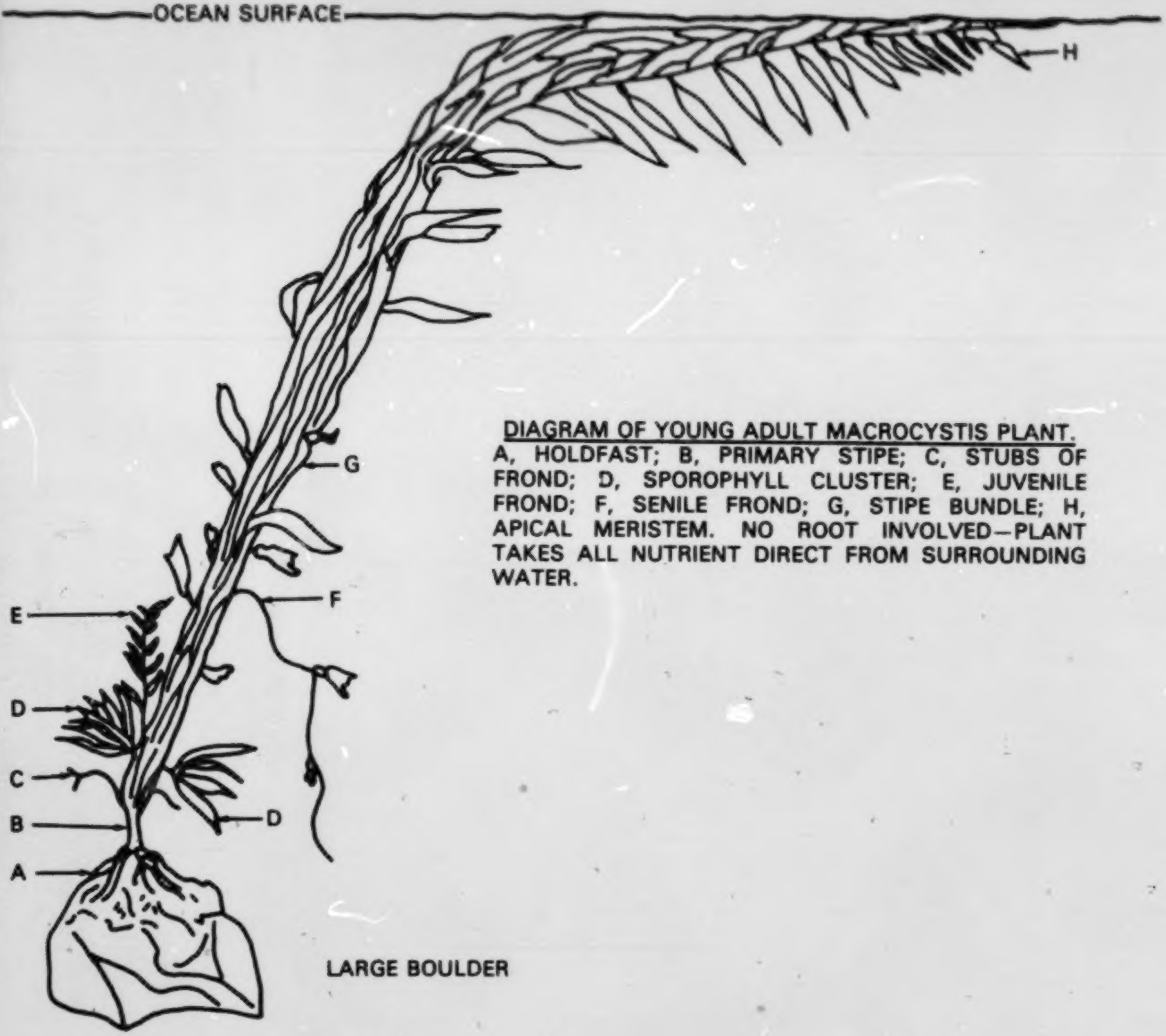
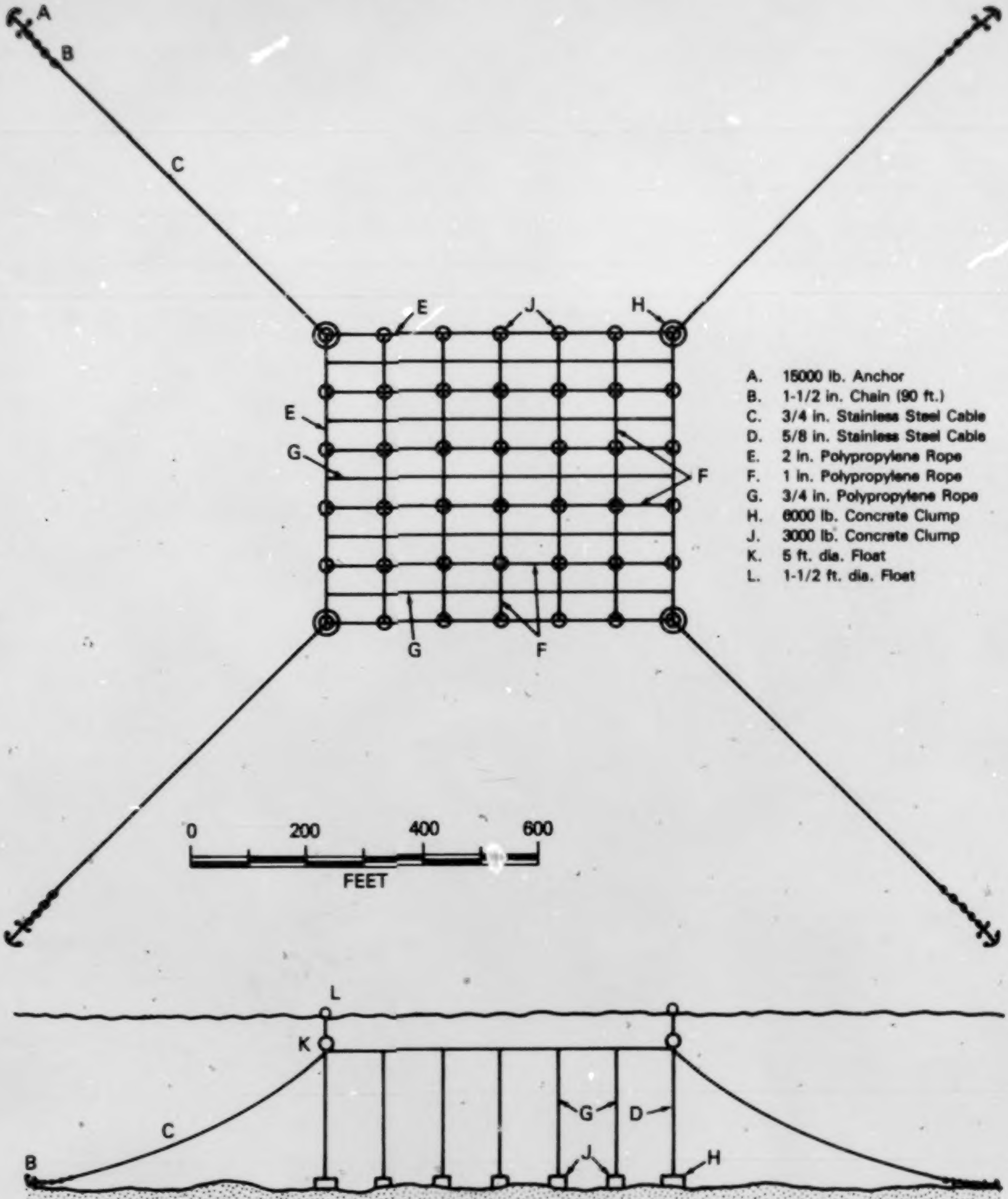


DIAGRAM OF YOUNG ADULT MACROCYSTIS PLANT. A, HOLDFAST; B, PRIMARY STIPE; C, STUBS OF FROND; D, SPOROPHYLL CLUSTER; E, JUVENILE FROND; F, SENILE FROND; G, STIPE BUNDLE; H, APICAL MERISTEM. NO ROOT INVOLVED–PLANT TAKES ALL NUTRIENT DIRECT FROM SURROUNDING WATER.

Source: Concerning the Selection of Seaweeds, Reference 5.

FIGURE 11-3
HORIZONTAL AND PLANE VIEWS OF THE GRID SYSTEMS CONSTRUCTED BY U.S. NAVAL UNDERSEA CENTER OFF SAN CLEMENTE ISLAND AS A SUPPORT FACILITY FOR MOORING KELP TRANSPLANTS


A
B
C
E
J
H
E
G
F
G
F
A. 15000 lb. Anchor
B. 1-1/2 in. Chain (90 ft.)
C. 3/4 in. Stainless Steel Cable
D. 5/8 in. Stainless Steel Cable
E. 2 in. Polypropylene Rope
F. 1 in. Polypropylene Rope
G. 3/4 in. Polypropylene Rope
H. 6000 lb. Concrete Clump
J. 3000 lb. Concrete Clump
K. 5 ft. dia. Float
L. 1-1/2 ft. dia. Float
0
200
400
600
FEET
L
K
C
G
D
B
J
H

SOURCE: Evaluating Oceanic Farming of Seaweeds as Sources of Organics and Energy, W.J. North, West Indies, 1975. Reference 11.

content of 4,400 Btu per dry pound (2,440 Kcal/Kg). If proper harvesting techniques are employed, the fronds should regenerate from the severed stipes, necessitating only one real "planting" operation. Harvesting operations use ships that cut and collect the kelp, later washing and chopping it as it comes on board. Upon arriving at the wharf, sea water is used to pump the macerated seaweed to processing sites.[10/]

Three small experimental MF's have already been established off the California Coast: one located off San Clemente Island, 60 miles (97 Km) from the mainland, a second off Crystal Cove [about one mile (1.6 Km) off the California Coast], and a third near a pinnacle formation named Ship Rock, off Catalina Island. The San Clemente structure was the first and largest, totalling seven acres (3.5 hectares) while the subsequent "farms" have been smaller (Crystal Cove is 100 feet (30 m) on each side). All the grids are located in deep water replete with strong currents and substantial swells. Taken together, the three experimental farms have demonstrated some universal accomplishments:

- Macrocystis pyrifera can be transplanted to and maintained on a grid composed of holding lines at an exposed, open-ocean site;
- None of the three farms have been subjected to the heavy grazing pressures found at natural, coastal kelp beds; and
- Colonies of juvenile kelp plants have appeared naturally on the tops of the submerged lines and buoys, thus suggesting that natural maintenance of the stand can be realized on open-ocean farms.

Overall, however, the Ocean Farm Project is still in its infancy, and while some success has been demonstrated, still other objectives remain to be achieved. These include:

- The ability of the grid structure to weather open-ocean storms has not been adequately tested. To date, at least one grid has shown structural failure, and it is difficult to draw conclusions, since the two other structures have been destroyed by vessel passage;
- The ability of farm plants to be repeatedly harvested without tearing loose from the mesh has not been demonstrated;
- The mooring lines of the grid structure have entangled the kelp fronds, holding them down and frequently destroying the attachment to the plants through chafing actions. Wooden beam moorings used in later operations have greatly reduced this problem;
- Frond growth rates have been inferior in the deep water settings of the rafts. Evidence indicates that this slow growth is caused by lack of dissolved nutrients; and
- Encrustation problems have developed with some of the plants, but there is indication that this may be due partially to slower growth rates.

The major concerns involve development of an adequate grid design to weather various open-ocean conditions and the design of a fertilizer system to supply the necessary nutrients which are absent in an open-ocean environment. The grid structure is continuously being modified to offset stresses encountered in test conditions and, so far, results have indicated that these structural problems can be solved. For the second problem, fertilization, there are two areas open for investigation: direct nutrient addition and artificial ocean upwelling.

Surface waters of the open sea typically display low levels of plant nutrients such as phosphate and nitrate ions and, thus, nutrient renewal might be a serious problem for an energy farm moored in deep water.[12] At the Crystal Cove experimental farm, an attempt was made to fertilize the Macrocystis transplants by means of leachate devices which released nutrients over time to the surface. Unfortunately, adverse weather broke these devices and their replacements. A greater drawback to this method, however, is the potential for depletion of valuable land-based fertilizer resources, such as phosphorus, through open-ocean application where a substantial percent of the fertilizer is nonrecoverable. Thus, attention has been focused on the use of artificial deepwater upwelling at the farm site through mechanical pumps which will circulate nutrient-rich waters near the surface. These deep ocean waters contain a far greater concentration of nutrients than surface levels; phosphate concentrations of up to thirty times the surface water concentration have been found at depths of 300 feet (92 m).[11/] This upwelling of cold water is also desirable because at lower latitudes surface waters are too warm for optimal growth. Present plans call for upwelling water from a depth of 500 to 1,000 feet (153 to 305 m).

As a three-phase effort, the Ocean Farm Project is currently involved in Phase I which is directed at exploring and establishing the technological and economic feasibility of the ocean farm concept by the 1979 to 1981 time period. The second part of the project, determined by the success of earlier efforts, will attempt to establish a 1,000-acre (400-hectare) farm in the Pacific and another in the Atlantic. Current tasks have included site surveys to determine potential marine farming locations in general Pacific and Indian Ocean areas.[13/]

These site surveys have determined there are at least 10 candidate ocean farm sites that, from cursory examination, appear to be well suited for future consideration. A particular potential area is the Hawaiian Archipelago, which consists of 16 individual sites, totalling approximately 3,355 square miles (8,689 Km^2).

Farms in these locations would utilize existing shoals and islands to minimize deep moorings in large, open-ocean areas. If such areas demonstrate that biomass growth in the ocean can be supported under managed conditions, many benefits could be realized.

Macrocystis may be used for its fertile, chemical, and fibrous components as it has been in the past, or it may be converted to synthetic fuels by one or more conversion processes (the major one considered is anaerobic digestion). Regarding its value as food, *Macrocystis* is under study to determine its potential to produce a high-protein animal feed.[8/]

3. Biomass Residues

The United States each year generates an enormous quantity of organic waste. Municipal refuse is the most often cited, yet there is a greater abundance of organic solids manifested in the cellulosic wastes of agricultural and silvicultural operations and the manures generated on cattle feedlots and dairy farms. With the development of biomass conversion schemes from existing and proposed technologies, these residues are becoming increasingly attractive as energy sources. Principally, three categories of residue are viewed as potential energy sources within ERDA's "Fuels from Biomass" Program: (1) crop refuse from agriculture, (2) logging residue from silviculture, and (3) collectible manure wastes. Ease of collection and the normal destiny of the residue material must also be considered in the utilization of these materials for energy.

Residues from farming operations are produced seasonally, approximately 322 million dry tons (290 metric tons) of crop residues being generated each year.[14/] Forty-eight percent of this amount is residue from small grains and grasses, while an additional 35 percent is from grain corn and sorghums. Rice straw, cotton gin trash, and some sugarcane are among those crops partially wasted, burned in the field, or collected and disposed of. Some crop residue is used as a fuel at processing sites (three percent of the total residues). This includes sugarcane mill waste, called bagasse, which is combusted at mill sites to provide process energy. Of the total crop residues, however, almost 75 percent is returned to the soil.[*] While controversy exists over what fraction can be removed for energy conversion without adverse environmental impacts, this category represents the largest potential residue energy feedstock. Including contributions from other categories, approximately 278 million dry tons (250 metric tons) of crop residue are thus considered available, collected during normal operations, or realistically collectible.

A second abundant source of biomass waste is that of logging residue and, to a similar extent, pulp and papermill residue. Logging residue is generated by common timber practices which utilize only the trunk of the tree, leaving behind large secondary items and bark (when onsite debarking takes place). Mill residue is that generated at mill sites of lumber, plywood, and pulp industries. Less than half the volume of a log at a mill ends up as lumber or plywood; the remainder is comprised of items such as bark, slabs, edgings, cores, and sander dust. However, the focus of biomass energy conversion is on logging residue left in the forest. This portion comprises 33 percent of the total wood residue generated each year from both forestry and mill operations. This residue so far has found little sustained use because of its scattered origin and the cost of delivering it to a point of use.

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[*] This is a valuable disposal method. Roller reports that leaving grain residue on the land results in approximately a 25 percent nitrogen return, a 40 percent phosphorus return, and a 75 percent potassium return.3/ Returning this cellulosic waste to the field also provides soil conditioning, since fibrous residue in the soil allows aeration and serves as a source of organics.

A third category of abundant waste is that of manure which originates from feedlot cattle, swine, sheep, and poultry operations. Approximately 36 million dry tons (32.4 metric tons) of manure are generated in these and similar operations each year. Of this total, about 26 million dry tons (23.4 metric tons) are considered collected or readily available. It is important to distinguish between confined feedlot and range-fed procedures in this case. Manure accumulating on range land is more difficult to collect than manure accumulating in confined operations where collection of wastes for disposal is a necessity. Manure collected under feedlot confinement may be stored in piles for more than six months at a time, and some large operations provide shelter for it until it is used or disposed of. A common practice is to sell or trade manure as fertilizer to nearby farming operations. Where disposal is required, lagooning is the method most often employed.

To assess systematically the quantities of waste generated and/or available for energy conversion, a national residue inventory has been initiated through the support of ERDA and the National Science Foundation (NSF).[14/] Intermediate results have been reported, compiled from a national, county-by-county computer data base pertaining to residues of crops, forest and wood products and livestock and poultry manures. A summary of these findings is given in Table II-1.

The residue inventory includes crop residue both in the field and at packing sheds, but excludes food processing wastes other than bagasse and sugarbeet pulp. It also excludes hay, forage, greenhouse, and experimental crops. In the case of manure, only those produced in confinement are included. In the inventory of forestry residues, mill and logging wastes are considered. It should be realized that the net quantity of residue available is only a fraction of the total produced. This is due to the existing uses for some residue classes which restrict their availability for other applications, such as energy conversion. Table II-2 summarizes current residue disposition.

TABLE II-1
AGRICULTURAL RESIDUE GENERATED
[10^6 DRY TONS (10^6 METRIC TONS)]

	TOTAL	AVAILABLE	COLLECTED
Crop	322 (292)	278 (252)	7 (6.3)
Manures	36 (33)	26 (24)	26 (24.0)
Forestry	116 (105)	114 (103)	76 (69.0)
Total	474 (430)	418 (379)	109 (99.3)

TABLE II-2
RESIDUE DISPOSITIONS
[10^6 DRY TONS (10^6 METRIC TONS)]

	CROP	MANURE	FORESTRY	TOTAL
Returned to Soil	237 (215.0)	25 (23.0)	-	262 (238)
Fed without Sale	61 (55.0)	-	-	61 (55)
Sold	13 (12.0)	5 (4.5)	38 (34)	56 (51)
Fuel	9 (8.2)	-	19 (17)	28 (34)
Wasted	2 (1.8)	6 (5.4)	59 (54)	67 (61)
Total	322 (292)	36 (33.0)	116 (105)	474 (439)

Source: An Evaluation of the Use of Agricultural Residues as an Energy Feedstock, Ref. 14.

Assuming 7500 Btu per dry pound (4200 Kcal/Kg) of biomass residue, the total collectible wastes of 474 million dry tons (426 metric tons) represent a potential energy return of over 7×10^{15} Btu, or approximately one percent of the total current energy needs of the U.S.[6/] Collection systems are now available for all areas of biomass residues - crop, logging, and manure wastes. However, the economics of collecting and processing such residues will determine, in part, the amounts available for near-term energy use.

C. Conversion Processes

1. Thermochemical Conversion

Thermochemistry, by definition, is the utilization of heat to bring about chemical reactions between substrates or within a substrate through rearrangement of molecular structure. The goal of thermochemical application to biomass is the production of carbonaceous gases, oils, and combustible char which can be used as fuel in other applications and which, as secondary fuels, have higher heating values than the original biomass material. As in all biomass conversion processes, the primary material for conversion is the cellulosic matter of the biomass.

The following subsections describe conversion processes available for use with biomass feedstocks. All of these processes have been applied to other materials such as coal and solid waste (which has a high cellulosic content after separation from inorganic components); however, much of their application to biomass has been isolated to laboratory scale projects used to determine feasibility. To date, only a few thermochemical biomass conversion projects have taken place on a commercial demonstration scale.

a. Pyrolysis

Pyrolysis is the chemical decomposition of substances by the action of heat in the absence of oxygen at atmospheric pressure. When organic materials are subjected to pyrolysis, three types of fuel are produced in various quantities: tar and oils, char, and carbonaceous gases. The feed-type, preparation, and reaction temperature determine the relative yields of each product, and the rate of heating can influence the composition of the gas: high heating rates correspond to an increase in carbon monoxide and a decrease in carbon dioxide.

The use of pyrolysis in biomass conversion has largely been examined in light of large-scale pyrolysis projects undertaken in waste resource recovery. After separation from inorganic components, municipal waste is found to be quite similar to biomass in cellulose content; therefore, application of pyrolysis to biomass is not without precedent.

Laboratory studies have demonstrated the pyrolysis of various biomass materials, among them bovine (cow) manure, crop waste, wood waste, and paper waste. All have been effectively converted to chars, oils, and gases. Simple procedures have used a milled and dried feedstock, swept by helium down a long iron tube that was progressively heated to 932°F (500°C) along its length.[15/] More advanced procedures have employed batch feeding [50-100 lbs (22-45 Kg)] to a stainless steel, fixed-bed retort which heated the material to the desired temperature in an air-deficient atmosphere. The pyrolysis products then were passed through a water solvent recovery train where tar and heavy oils, lighter oils, and tar fog and mists were consecutively removed. Acid and alkali wash towers removed gaseous products such as ammonia, hydrogen sulfide, carbon dioxide, and hydrogen chloride not removed in water traps.[19/]

Table II-3 presents a summary of the pyrolytic reactions of bovine manure, rice straw, and pine bark. About 27 percent of the total oil yield from cow manure was a lighter, predominantly aromatic fraction, consisting of about 87 percent benzene, toluene, and zylenes. The recovered gas was typically a mixture of 25 percent CO_2, 18 percent CO, 27 percent H_2, 22 percent CH_4, and 7 percent other hydrocarbons (all based on a 1652°F (900°C) pyrolytic reaction).[16/] The char or residue was incompletely reacted biomass, which could be combusted as a fuel. Because biomass has an inherently low sulfur content (approximately 0.3 percent), an advantage of these biomass-derived fuels, such as char and oil, is the consequent low-sulfur content of the fuel.

TABLE II-3
PYROLYTIC PRODUCTS OF VARIOUS FEEDSTOCKS

		BOVINE WASTE	RICE STRAW	DRY PINE BARK
YIELDS (PER TON OF FEED)	Temp [°F (°C)]	1,650 (900)	390-1,290 (200-700)	1,650 (900)
	Gas [ft³ (m³)]	13,940 (395)	5,981 (170)	20,154 (572)
	Oil [gal (l)]	13.0 (49.3)	11.0 (41.7)	5.5 (20.8)
	Char [lb (Kg)]	726 (330)	800 (364)	630 (286)
HEATING VALUES	Feed [Btu/lb (Kcal/Kg)]	7,110 (3,942) 3.6% moisture)	6,080 (3,371)	8,350 (4,629)
	Gas [Btu/ft³ (Kcal/m³)]	450 (3.2)	662 (5.1)	472 (3.4)
	Residue [Btu/lb (Kcal/Kg)]	7,290 (4,042)	7,380 (4,091)	12,920 (7,163)
	Oil [Btu/gal (Kcal/ l)]	0.1 x 10^6 (6,649)	———	———

Source: Schlesinger, M.D., et al, "Energy from the Pyrolysis of Agriculture Wastes," Symposium: Processing Agricultural and Municipal Wastes, AVI Publishing Co., Westport, Conn., 1972, Ref. 16.

The disadvantages of pyrolysis are the fairly high technical skills required in operation and the requirement of a dry feedstock (wood waste often contains 50 percent moisture). However, an advantage when compared to more advanced thermochemical systems such as hydrogenation or gasification is the absence of costly, high-pressure equipment.

b. Producer Gas Generation

The producer gas, or low Btu gas generator, is a variation of the technology of pyrolysis. In a gas producer, the solid fuel (i.e., biomass) is burned on a packed bed with a limited air supply at a temperature in excess of 2010°F (1100°C).[17/] A self-sustaining partial combustion of the biomass takes place, producing sufficient heat which allows pyrolytic reactions also to occur. The result is a combustible solid (char) and a hot, combustible gas composed principally of carbon monoxide, hydrogen, nitrogen, and carbon dioxide. The hot gas is suitable for burning in applications similar to natural gas if a proper nozzle and filtering mechanism are employed, or, after cooling, it may be applied to a small spark ignition or diesel engine.[17/]

Producer gas was used extensively in the early part of this century, when many towns and cities had a "town gas" or "coal gas" plant which supplied gas for lighting and other residential and commercial uses.[18/] Gas producers using biomass as fuel also were developed using such items as wood waste and straw. In 1948, the U.S. Department of Agriculture (USDA) Laboratory in Peoria, Illinois, burned coarsely ground corn cobs to produce a gas with a heat content of 159 Btu/ft^3 (1.14 Kcal/m^3). Typical gas composition was 9 percent CO_2, 20 percent CO, 15 percent H_2, 3 percent CH_4 (methane), and 53 percent N_2.[17/] Depending on the scale and operating variables, pyrolytic oils could also be produced.

A commercial, 50-ton/day (45 metric ton/day) demonstration producer-gas plant that operates on sawmill wastes is located in a wood yard in Cordele, Georgia, and has been in operation for more than 2½ years.[19/] The char produced is sold on the commercial carbon market. The oil produced is used in an oil-fired kiln drier; a portion of the gas is used to dry the feed and the remaining gas is flared. This large demonstration plant is the result of work done on pyrolysis by the Georgia Tech Engineering Experiment Station (EES). A six ton/day (5.4 metric tons/day) pilot plant was constructed in 1972 on the Georgia Tech campus for the processing of various wastes including peanut hulls, wood chips, pine bark, and cotton gin wastes. In this design, waste is placed in a receiving bin where it is then fed to the reactor by a conveyor belt. The system is capable of processing 300 to 500 pounds (136 to 227 Kg) of waste/hour depending on the feed-type and moisture content.

The gas producer, because of its simple boiler design, is also being investigated for use in small or mobile units. The University of California at Davis is experimenting with a small gas producer that uses crop residues for fuel. Though operating variables are still being tested, a 4-cylinder, air-cooled engine has been run some 3 to 4 hours with few problems, supplying shaft horsepower to an electric generator.[17/]

In the past, a large number of mobile gas producers were developed for use on automobiles, trucks, and tractors using charcoal as fuel. Though vehicle power may not be the desired goal, the portable unit would be capable of producing shaft horsepower for other uses. Coupled with potential mobility, the producer gas generator has the further advantage of requiring little technical expertise in its operation. For these reasons, application of the producer gas generator to crop residues at the source site (i.e., the farm) is feasible, with certain limitations. As a self-sustaining, partial combustion system, the gas generator does demand a drier feedstock than is required in other thermochemical processes where an external heat source is supplied.

c. Hydrogenation

Hydrogenation is a chemical process characterized by the addition of hydrogen to organic compounds to obtain an oil with a high hydrogen to carbon ratio. It is an exothermic reaction, but in the absence of a suitable catalyst it proceeds at a negligible rate, even at elevated temperatures. For this reason, high temperature, catalysts, and high pressure often characterize the hydrogenation process. In converting cellulosic materials to oil, the most important overall reaction is the splitting out of oxygen in the degradation of the large cellulose polymers to form smaller molecules with a higher hydrogen to carbon ratio.

The Bureau of Mines has successfully demonstrated the conversion of various biomass materials (including urban refuse, agricultural wastes, sewage sludge, wood, lignin, and cow manure) to low sulfur oil. The procedures used are outgrowths of research applied to the production of low sulfur liquid fuels from coal. Similar processes applied to biomass have used carbon monoxide or synthesis gas ($CO + H_2$), water, and catalyst to hydrogenate cellulosic feedstocks.[20/21/22/]

In one series of experiments, biomass material, water, and catalyst were charged to a 500 ml stainless steel autoclave. Carbon monoxide was added to the desired pressure, and heat and agitation were supplied by a rocking furnace. The reactions took place at temperatures from 480°F to 840°F (250°C to 450°C) and were accompanied by pressures reaching 5,000 psig.[20/] An alternate procedure employed the less expensive synthesis gas ($CO + H_2$) in place of the pure carbon monoxide and water mixture; also included was a combination cobalt molybdate-sodium carbonate catalyst. This latter series of experiments demonstrated that manure (cow) with a moisture content of 35 percent could successfully be hydrogenated to an oil.[22/] Other lab-scale projects have yielded manure-derived oil as well as oils from such materials as cornstalks, rice hulls, corn cobs, and pine bark. Up to 99 percent of the starting material [usually 1.6 oz (50 gms)] has been successfully converted.[20/] Table II-4 presents the analyses of some biomass-derived oils and compares them with a crude fossil-oil analysis.

The Energy Research and Development Administration is presently funding construction of an experimental facility at Albany, Oregon, which will continue investigating the processes for deriving synthetic liquids and gases from wood waste.[23/] The Albany facility is designed essentially after an earlier Bureau of Mines procedure which converted organic material to oil at 570°F (300°C) under carbon monoxide and steam pressure. The pilot plant is designed to handle from 1 to 3 tons (0.9 to 2.7 metric tons) of wood chip waste per day, with expected yields of from 650 to 1950 pounds (295 to 886 Kg) of oil daily. The facility will also have head-end and tail-end processing equipment to allow investigation of several types of feed material and variations of the basic procedure.

d. Hydrogasification

Hydrogasification is a thermochemical process that produces chiefly methane by the degradation and saturation with hydrogen of higher organic compounds. These processes have been previously applied to coal to produce synthetic natural gas (SNG). As an extension of research concerning coal gasification, hydrogasification has been applied to cellulosic wastes, successfully yielding SNG.

In a procedure developed at the Bureau of Mines, dried cow manure (2.5 percent moisture) was placed in a batch autoclave (0.7 liter) containing an atmosphere of pure hydrogen.[24/] The starting material was then subjected to high heat [1020°F (550°C)] and pressure [1800 psi (1.24×10^{8} dyne/cm^{2})] for one hour in a rotating furnace.

TABLE II-4
OIL COMPOSITION OF HYDROGENATED CELLULOSIC WASTES
(WEIGHT %)

	CARBON	HYDROGEN	NITROGEN	SULFUR	OXYGEN	HEATING VALUE Btu/GAL
Cornstalks[a/]	70.1	7.3	0.5	0.11	22	–
Bovine Manure[a/]	78.6	9.5	4.2	0.37	7.3	–
Bovine Manure[b/]	81.5	9.9	4.4	0.10	4.1	110,680
Crude Oil	84-87	11-14	0.2	0.2	—	139,000

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a/ Source: Fuel from Agricultural Wastes, Reference 24.

b/ Source: Conversion of Manure to Oil by Catalytic Hydrotreating, Reference 22.

ULTIMATE ANALYSIS OF DRIED COW MANURE

	WEIGHT %
Carbon	35.4
Hydrogen	4.2
Nitrogen	0.7
Sulfur	0.2
Oxygen	23.5
Ash	36.0

Source: Hydrogasification of Cattle Manure to Pipeline Gas., Reference 24.

The resulting gas was a mixture of approximately 30 percent hydrogen, 1 percent carbon monoxide, 38 percent carbon dioxide, 20 percent methane, 7 percent ethane, 4 percent higher hydrocarbons, and less than 0.2 percent hydrogen sulfide.

Hydrogasification tests using dried cow manure have also been run in a free-fall dilute-phase (FDP) reactor.[24/] The solid residence time is only two seconds, but because of the greater accessibility of the solid to hydrogen, the reactivity is increased; at 1020°F (550°C) and 1000 psi, the amount of carbon gasified was 51 percent. After scrubbing out CO_2, it was possible to obtain a gas with a heat content in excess of 1000 Btu/ft^3 (7.15 Kcal/m^3), due to the high ethane content.

Unfortunately, the hydrogasification process has some drawbacks, including the need for costly, high-pressure equipment, consumption of expensive hydrogen gas, and a necessary high energy input. A hydrogenation plant at Albany, Oregon, plans to investigate some hydrogasification procedures but, in relation to other thermochemical conversion systems, hydrogasification is the least developed of laboratory-scale projects.

2. Bioconversion Systems

Bioconversion is a term used to denote biomass conversion processes that are accomplished through the action of microorganisms. The necessary chemical reactions are precipitated by the action of enzymes supplied by biological systems. Thus, bioconversion is not simply a chemical process, but one in which a "healthy" reaction environment is essential for its success.

The following sections describe two bioconversion processes considered as viable technologies for economically converting biomass into useful fuel. The first describes anaerobic digestion which can convert organic matter into methane gas. The second deals with anaerobic alcohol fermentation, a system utilizing a group of organisms that converts carbohydrates to ethanol.

a. Anaerobic Digestion

Anaerobic digestion is a form of the more general process of decay, whereby organic matter is decomposed from complex forms to simpler, more stable compounds. In the anaerobic digestion process, decomposition proceeds in the absence of air (anaerobic) with the resulting catabolic products including a gas mixture of methane and carbon dioxide.

The most popular use of anaerobic digestion in the U.S. is for treatment of municipal sewage, although other countries (e.g., India) have employed it as a source of methane.[25] Its primary function in waste treatment is the reduction and stabilization of sewage solids which may be land-filled when biologically stabilized. The gas formed in these processes is a mixture of about 60 percent methane, 40 percent carbon dioxide, and small amounts of ammonia, hydrogen, hydrogen sulfide, mercaptans (organic sulfur compounds), and amines.

The primary candidates for bioconversion as an energy source have been the animal manures, mostly cattle, produced in feedlot and dairy operations. Other cellulose-containing materials have also been suggested and their feasibility shown in a number of cases. Various biomass feedstocks have included manure, newsprint, grass, algae, seaweed, and dogfood. Both salt and fresh-water media have produced successful results. The advantage of the digestion process is that it is relatively simple, occurring at atmospheric pressure and slightly elevated temperatures. The main hindrances are the heat energy that must be supplied and the sensitive environmental parameters that must be maintained.

The anaerobic digestion process takes place in two stages and involves two groups of bacteria: "acid formers" and "methane formers." The acid formers comprise the initial step of the operation, converting complex organics such as fats, proteins, and carbohydrates into simpler compounds, chiefly organic fatty acids. In the second stage, the organic acids are converted into gaseous end products by the methane formers. These organisms constitute several different groups, each characterized by its ability to ferment only particular organic compounds. The most important methane formers unfortunately are among the slowest growers, and solids retention times of four or more days in the digester are required for their growth.[26/]

The basic design of an anaerobic digester is essentially similar throughout different systems. An influent sludge, consisting of approximately 10 percent solids in a water solution, is fed into an air tight container containing anaerobic bacteria. These bacteria ferment the organic portion of the solids, usually at two optimum temperature ranges: mesophilic [86-99°F (30-37°C)] and thermophilic [120-135°F (49-57°C)]. Treatment proceeds more rapidly at the latter range, but more heat energy is required. The pH of a digester should be maintained near 7--essentially a neutral medium. The degree of digestion occurs according to temperature and the very important solids retention time (SRT). Minimum SRT values are 7.5 days for 95°F (35°C); 10-30 days are usually employed in municipal sludge handling.

When applied to biomass, anaerobic treatment will tolerate a wide variety of materials, though some are better suited than others. In general, most cellulosic materials can be digested given various pretreatment processes, but cellulose is quite resistant in untreated form. For these reasons manures are attractive candidates, since much of their content has already undergone partial degradation, even if only through mastication.

In general, anaerobic treatment of cattle manures will produce from 6 to 9 cubic feet (170 to 225 liters) of methane per pound (454 gm) of dry solids.[14/]

An experimental facility to investigate application of cattle manure to anaerobic treatment is presently being constructed at the U.S. Meat Animal Research Center, Clay City, Nebraska.[27/] The plant will consist of a 12,230-gallon (46,350 l) fermenter equipped to handle 350 to 400 pounds (160 to 180 Kg) of manure per day, equivalent to that produced by 10 to 12 beef cattle. The plant will not produce sufficient methane to operate itself, though larger systems are estimated to be energy self-sufficient. A primary objective of the plant is to investigate the possible feed value of digested solids from ruminants. The relatively high protein content (20-25 percent by amino acid analysis) of digested output material indicates that its value as a feed ingredient may significantly exceed that of the methane produced, though it is not a certainty. Indeed, the solids are also valuable as an organic fertilizer, possessing a nutrient content 3 to 4 times more concentrated than that of raw manure.

b. Alcohol Fermentation (to Ethanol)

Alcoholic fermentation is a familiar process which has been utilized by man for centuries to produce the beverage ethanol. However, ethanol is also a combustible organic with a heat content of 12,810 Btu/lb (7100 Kcal/Kg) as well as an important chemical feedstock.[28/] Materials required for conversion are sugars or substances that can yield them (polysaccharides), and the proper bacteria (yeast cells). Since the sugars needed for biosynthesis of ethanol can be derived from cellulose, potential raw materials include a variety of biomass (carbohydrate) materials such as agricultural and forest residues. Manures, on the other hand, are not good candidates for this process because of their high amino acid content, which is best handled by anaerobic digestion.

The conversion of cellulose to ethanol first requires hydrolysis to simpler sugar units. This may be accomplished by acid or enzyme catalysis. With many woody materials, hydrolytic conditions must be severe (e.g., high heat) for reaction to take place, depending on the crystallinity of the cellulose fiber and lignin content (wood lignins are predominantly aromatic compounds which form an insoluble net around cellulose, hindering decomposition). In chemical treatment, hot mineral acids hydrolytically degrade cellulose into monomeric sugar units (d-glucose) which can then be fermented to ethanol by yeast cells.

Microbial, or enzymatic, degradation of cellulose is similar to acid hydrolysis except that enzyme attack at the oxygen linkages of the cellulose polymer is limited due to the relatively large size of the enzyme molecules, which have difficulty reaching the reaction sites. Enzymes that hydrolyze cellulose are termed cellulases, and the bacteria that manufacture them are different from the fermenters. Enzyme actions are catalytic and, consequently, enzymes are not consumed by the reaction. The development of a recovery and recycle system for the spent transpose enzyme therefore is of great importance.[29/]

In the fermentation process itself, the chemical reactions involved are quite complex, but the overall reaction in the production of alcohol from glucose may be given as:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \xrightarrow{\text{Yeast}} \underset{\text{Ethanol}}{2C_6H_5OH} + 2CO_2\uparrow$$

The process may take place either in a batch or continuous-growth reactor. Both systems require monitoring and adjusting of various conditions, including pH level, nutrient addition, and temperature. Fermentation is an anaerobic process, although very small amounts of oxygen have been shown to promote cell growth.[29/]

In a batch-load procedure, the substrate to be fermented is placed in a reactor tank, proper adjustments are made, the innoculum (yeast) is added, and the tank is closed. Fermentation proceeds at approximately 63°F (35°C) until the yeast cells stop growing due to product inhibition (the alcohol level eventually becomes toxic). Then the alcohol is removed by distillation. When using the continuous growth process, the problem of product inhibition is avoided. Sugar is fed into the fermenter continuously at a fixed rate, while the alcohol is continuously drawn off under reduced pressure. A steady state system is thereby attained whereby products and reactants are kept at optimum levels, allowing the reaction to continue at a measured rate. Both systems will produce alcohol solutions of from 8 to 12 percent, which may then be concentrated to 95 percent by fractional distillation.[30/]

Bioconversion to alcohol of various biomass materials cannot be viewed as an exotic technology, for the distillary industry has successfully applied it on a large scale for many decades. Present application of alcohol fermentation as an energy source is isolated primarily to laboratory studies with emphasis largely placed on enzyme hydrolysis with a recycle system. Studies have shown that a high rate of conversion (75 percent) can be obtained from the cellulose of delignified wood when treated for 40 hours with the enzyme produced by the fungus *Trichoderma viride*.[29/] Approximately 70 percent of these sugars produced from cellulose hydrolysis were fermentable to ethanol. A recycle system for the enzyme has not been perfected, but it has been proposed that 95 percent of the enzyme can be recovered through an adsorption system.[30/]

3. Combustion

Combustion is a conversion process that directly converts biomass into usable heat rather than into a secondary fuel. When dried to a proper moisture content, all biomass will undergo combustion, including manure which serves as a heat source in many of India's private dwellings. As a fuel for direct combustion, however, wood and woody refuse have been and are the most feasible biomass feedstocks. For example, in 1969, 43 percent of the wood cut in the world was used for fuel, while 34 percent was used for saw logs and railroad ties.[31/] Accordingly, when discussing biomass fuels for combustion, the focus is on wood, although it should be noted that other biomass materials such as agricultural residues are also suitable, having similar heat contents.

The heating value of wood is dependent on its fiber, resin and moisture content. Wood fiber has a heating value of 8300 Btu per pound (4600 Kcal/Kg), while the value of resin is 16,900 Btu per pound (9370 Kcal/Kg). Thus, a small proportion of resin in wood will considerably increase its fuel value. The wood barks and, in general, the softwoods have higher resin contents and, therefore, higher heating values. Some typical values in Btu per pound (and Kcal/Kg) (dry weight) for bark and wood are shown below: [31/]

Species	Heating Value	
	Wood	Bark
Douglas fir	9,200 (5,100)	10,100 (5,600)
Douglas fir	8,800 (4,900)	10,100 (5,600)
Western hemlock	8,500 (4,700)	9,800 (4,900)
Ponderosa pine	9,100 (5,000)	--- ---
Western red cedar	9,700 (5,400)	8,700 (4,800)
Red alder	8,000 (4,400)	8,410 (4,660)

For a model of large-scale, industrial use of wood as a heat and energy source, the forest industries serve as the best example. These various operations (pulp/paper, sawmill, and plywood manufacturers) supply some 20 to 50 percent of their needed energy from wood wastes, while purchased energy from fossil fuel utilities supplies the remainder.[32/] In fact, the forest industry seeks energy self-sufficiency in many sectors through the use of logging and mill residue. However, the potential high costs involved in the collection and handling of forest residues generated by timber operations have caused their historical use as fuel to be prohibitive, at least in relation to the lower costs of fossil fuel.

The residue flow is well established in the forest industry, the traditional source being mill waste which includes bark, chips, sawdust, end trims,and slabs. At the mill site, a "hog" is used to grind up the large residue to particular size, but the term "hogged fuel" also encompasses such material as sawdust and wood shavings. Hogging is an essential step in the fuel enhancement process which may also include cleaning, since bark often contains sand, and drying.

The technology of large, wood-burning boilers is well developed and, consequently, hogged fuel can be fired in many different boiler designs. One of the more efficient models is the spreader-stoker, which is suitable for a wide range of capacities. Here, the hogged fuel is introduced above the furnace grate by either a pneumatic or mechanical spreader. Part of the fuel is burned in suspension, and the remainder drops to the grate where burning is completed. Spreader-stokers are used with small boilers of capacities as low as 25,000 pounds (11,000 Kg) of steam per hour to large plants with capacities in excess of 500,000 pounds (227,000 Kg) steam per hour.[33]

Steam generated by a boiler can be used in a turbine for production of electricity. The forest industry normally uses 10 to 20 percent of its process steam energy for electrical production, while the remainder is used for drying, heating, and hot pressing. In this way, steam which is run through a turbine is exhausted for use as process heat rather than wasted in a condenser. Under these conditions, the relative efficiency of heat recovery from fuel combustion can reach 75 percent.[34] However, if electricity is the sole product of the process, the overall thermal efficiency is only about 38 percent, the remaining heat being vented to the atmosphere. Utilities that use wood for electrical production are rare today with the exception of a few standby facilities. One wood-fired powerplant rated at 32 MW is located in Eugene, Oregon, and it supplies electricity on a regular basis.

The major constraints on using wood as a fuel for large-scale electrical generation are its difficulties in handling, collection and availability problems, and lower heat values as compared to fossil fuels. For example, the average heat content of dry wood is 8500 Btu/lb (4700 Kcal/Kg) while those of coal and oil are 1200 Btu/lb (6600 Kcal/Kg) and 21,500 Btu/lb (11,900 Kcal/Kg), respectively.

Moreover, assuming average boiler efficiency, electrical output rates per heat input are 10,000 Btu/kWh (2520 Kcal/kWh) for fossil-fired utilities and 12,000 Btu/kWh (3020 Kcal/kWh) when firing wood. Most new utility plants are rated at around 1000 MW. A facility of this size would require approximately 2000 tons (1800 metric tons) of wet wood or bark per hour. By comparison, the 125 to 250 tons (113 to 227 metric tons) per hour that most pulp mills use in manufacturing paper represent the major output of a forest and not residue alone.[34/]

Presently the forest industry and similar operations offer the best near-term potential for energy self-sufficiency through wood use. The fuel flow from mill waste is already established; what remains to be tapped is the abundant logging waste left on timbered land. If the total residues available from logging and mill wastes were utilized, self-sufficiency could possibly be achieved.

4. Direct Hydrogen Production

Photosynthetic species, whether terrestrial or aquatic, normally utilize sunlight for carbon fixation and the subsequent manufacture of carbohydrates. Photosynthetic growth is dependent upon gaseous CO_2 for terrestrial plants and concentrations of aqueous carbonate or bicarbonate ions for aquatic plants.

It has been observed that production of small amounts of hydrogen has accompanied photosynthesis, and consequently it has been determined that this is a result of incomplete or partial photosynthesis. The chemistry of this phenomenon is represented by the following equations:

(Step 1) Water photolysis:

$$2H_2O \xrightarrow{light} O_2 + \underset{\uparrow}{4H^+} + 4\ \underset{\uparrow}{e^-}$$

hydrogen ion
free electrons

(Step 2) Enzymatic action:
(hydrogenase enzyme)

$$4H^+ + 4\ e^- \longrightarrow 2H_2$$

Total reaction

$$2H_2O \xrightarrow{light} O_2 + 2H_2$$

Presently, there are two approaches envisioned for promoting this set of reactions. One is to encourage photosynthetic growth in a biomass species, such as algae, and simultaneously alter the conditions - to "trick", upset, or unbalance the natural metabolism - so as to maximize hydrogen production. The second is to isolate the key chemicals and enzymes involved in the process and then generate hydrogen via a controlled synthetic reaction.

The state of the art for this form of hydrogen production is at an early stage. The benefits of this biomass technology are not expected for the near term, and the results of basic research still are needed before the long-term energy production capabilities can be realistically estimated. Consequently, only the energy potentials can be discussed.

The efficiency of the overall process is a maximum of 10 percent, which if realized could produce approximately 2 watts per square foot of photosynthetic surface, or approximately

300 Btu/hr per acre (190 Kcal/hr/hectare). Research aimed at achieving these potentials is taking place along two lines. One is concerned with investigating the biochemistry of the photosynthetic process. This will hopefully lead to a substantial understanding of its basic elements, therefore allowing the design of controlled hydrogen producing systems.[35]

The second approach is to concentrate on the conditions that are known to promote algae hydrogen production and to alter them in ways that will optimize yield. Such experiments have been initiated at the University of California utilizing heterogeneous blue-green algae.[36] These organisms are thought to localize the evolution of the hydrogenase enzyme and are a logical choice for research. Successful application of these enzyme localizations to produce hydrogen gas is dependent on the use of extremely thin membranes, which presently cannot be manufactured. If the economics of this system are to compete with conventional energy sources, it has been estimated that the membrane material has to cost less than 50 cents a square foot ($\$5.30/\text{m}^2$).

D. Resource Requirements

Biomass production or conversion for the most part has not entered into commercial-scale application; consequently, resources of most applications can only be estimated. Because the "Fuels from Biomass" program has focused chiefly on individual areas of application, system resource estimates of integrated production and conversion schemes are few. In this section one integrated system is presented, that of marine biomass production and conversion. Other technologies presented are terrestrial biomass production and a wood-fueled steam electric plant.

Table II-5 lists material needs for a hypothetical marine farm and processing system. The baseline design consists of an ocean farm of one hundred thousand acres [a square approximately 12.5 (20.1 Km) on a side], located 100 miles (160 Km) off the coast of southern California. The productivity of this farm is estimated at 340 tons of wet harvest per acre per year (760 metric tons/hectare/year).

Conversion to secondary fuels entails processing and drying the harvested kelp, with eventual separation into volatile solids and salts. The resulting carbohydrate contents are anaerobically digested at 140°F (60°C) to generate synthetic natural gas (SNG). A conversion of 49 percent of volatile solids is assumed. The farm support subsystem consists of a large concrete platform which provides for living and work space. Also, a shore-based dock and repair facility are provided.

Table II-6 cites resources needed for a wood-fueled electric utility. These include the land and fertilizer requirements that are needed to sustain the wood supply consumed by the utility. These estimates do not take into account harvesting, processing, and transport machinery also required in an integrated production-conversion scheme. Such material needs are variable, being sub-

TABLE II-5
MARINE FARM RESOURCES

[10^5 Acres (405 Km^2) - Annual SNG Output = 2.21×10^{10} ft^3/yr (2.05×10^9 m^3/yr)]

Quantities in Thousand Tons

SUBSYSTEM	CONCRETE[a/]	STEEL	PLASTICS	OTHER[b/]	TOTAL
Cultivation	619	5.0	23.2	–	647.2
Harvesting	–	38.3	–	–	38.3
Processing	441	18.9	5.0	2.5	467.4
Support	68	0.3	–	–	68.3
Sub-Total	1128	62.5	28.2	2.5	1221.2
Mariculture	–	3.6	21.4	–	25.0
Total	1128	66.1	49.6	2.5	1246.2

a/ Concrete Density = 155 lbs/ft^3 or 2.1 $tons/yd^3$.

b/ Nonferrous and miscellaneous metals.

SOURCE: System Analysis of the Ocean Food and Energy Farm Project, Ref. 37.

TABLE II-6
MATERIALS REQUIREMENTS

ELECTRIC GENERATION	STEAM TURBINE
Steel	34.1 tons/MW_e
Concrete	153 tons/MW_e
Other	63.6 tons/MW_e
WOOD PRODUCTION	
Land	3.2 mi^2/MW_e
Herbicide	6 tons/MW_e/yr
Nitrogen	100 to 300 tons/MW_e/yr
Potassium	50 to 100 tons/MW_e/yr
Phosphorus	40 to 100 tons/MW_e/yr

Source: Analysis and Planning Support for ERDA Division of Solar Energy, Ref. 38.

ject to biomass species grown, plantation location and topography, and proximity between plantation and conversion facility (wood-fired utility).

The resources identified in each of the tables are conventional and should not be difficult to obtain. Shortages of these materials are not expected, except for the fertilizers which may have seasonal shortfalls (especially phosphorus). This problem would be aggravated by competition with food and fiber production. Since the marine farm structures will be assembled in the field, a surplus of materials may be needed. Conversely, the wood-fired boiler is delivered as a modular unit and only installation is required; thus, additional materials (except spare parts) should not be needed.

SECTION III

ENVIRONMENTAL IMPACTS

A. Impacts from Production of Biomass

The following sections are concerned with potential environmental impacts originating from the production of biomass for energy. Aside from marine cultivation, the managed growth of biomass is founded on the principles of modern farming and silvicultural practices. Consequently, environmental impacts of terrestrial biomass production likely are analogous to these established technologies, and the projected impacts of the energy plantation presented here draw from the literature on impacts of modern farming and forest management. The use of residues also relates to these modern activities, and the impacts of crop and logging waste are discussed in light of current management practices and disposal.

In the case of marine cultivation, little is known about suggested practices. Consequently, impacts must be estimated on the basis of assumed future implementation. Impacts associated with experimental marine farming systems have not been apparent, mostly due to their small scale; only the potential environmental impacts due to large-scale deployment of open-ocean raft systems have been discussed here. Since impacts of construction activity are of a different nature than those of operation, construction impacts also have been included in the assessment.

When reviewing the impacts of biomass production, it should be noted that in this discussion biomass is considered as an energy source. In this framework, biomass may be compared with other energy resource bases, namely, fossil and nuclear fuels. Residuals associated with exploitation of these latter energy resources also significantly affect air, water, land, and ecological quality. Accordingly, a proper perspective should be maintained between the impacts of biomass as an energy source and other traditional energy resources.

1. Impacts of Terrestrial Growth/Biomass Plantation

The impacts of growing biomass for its energy content, whether in the form of trees or crops, should be similar to those of existing agricultural or silvicultural activities, though perhaps of a different magnitude because of the scale involved in a so-called energy plantation. The principal impacts of farming operations are increased dust and sediment loads which, in turn, affect air and water quality. Silvicultural activities generate pollutants similar to those encountered in agriculture. In this case, however, airborne dust is not as chronic a problem: the major pollutant of concern is sediment loads to waterways.

a. Effects on Air Quality

Operation of an energy plantation will result in increased particulate levels caused by fugitive dust. These emissions are generated by a number of activities including soil cultivation, logging, harvesting, and heavy equipment traffic over unpaved areas. This impact will be of greatest magnitude when land previously in other uses must be newly cleared or tilled, especially if the soils are light and dry. Other sources of air pollutants will be aerial pesticide applications and combustion emissions from farm support machinery.

In agricultural tilling operations, dust particles from the loosening and pulverization of the soil are injected into the atmosphere as the soil is dropped to the surface. Dust emissions are greatest when the soil is dry and during final seedbed preparation. The dust emitted by agricultural tilling (per acre of land tilled) is directly proportional to the silt content of the soil and the implement speed. These emissions have been observed at between 56 lb/acre (62 Kg/hectare) and 78 lb/acre (88 Kg/hectare) during normal tilling operations for a variety of water and silt contents of the soil.[39/] Of these total dust emissions, i.e., those particles which drift beyond 25 feet (7.6 m) from the edge of the tillage path, about 40 percent have medium-range drift potential and about one-third are in the fine particle range [1,000-foot (300 m) drift to over hundreds of miles].

Besides planting and cultivation processes which disturb surface soils, dust emissions from unpaved road surfaces also are common in both agricultural and silvicultural (from fire and access roads) operations. In particular, unpaved trails and roads are the predominate fugitive dust sources in forestry operations. The emissions of dust from travel over unpaved surfaces (per vehicle-mile of travel) are directly proportional to the average traffic speed and to the silt content of the road surface. Emissions are reduced during periods of rainfall, but quickly return to normal levels. Observed dust emissions range from 10 to 56 lb/vehicle-mile (3 to 16 Kg/vehicle-km) for common equipment travel over these surfaces.[39/]

The other major potential air quality impact of biomass plantations (primarily those of agriculture) will be that of airborne pesticides. Their greatest influence, however, will come from subsequent soil runoff and residues rather than from aerial application or dust. Pesticides may be contained in airborne dust, but their role in fugitive dust impacts remains unclear.[40/]

Overall, air quality impacts related to both crop and forest cultivation will be similar; however, since tree rotation schemes require harvest of only 1/3 to 1/6 the total plantation area each year, heavy dust conditions caused by periodic harvest and exposure of soil should be somewhat reduced. The use of proper prevention schemes (such as windbreaks) will help mitigate dust emissions from these sources. In addition, management schemes -- specifically in agricultural operations -- which do not practice total crop residue removal will aid in alleviating heavy dust conditions caused by exposed soil surfaces. A particularly beneficial practice is the use of "no-till" management which alleviates the dustfall associated with tilling operations (in no-till farming, only the tops of plants are harvested and the root structures are preserved).

b. Effects on Water Quality

The major water quality impact of intensive crop or forest cultivation is sedimentation in surface waters caused by runoff from exposed soils. Large energy plantations could contribute significant sediment loads whose impact would be at least equal to that from conventional crop or forest lands and could be significantly higher due to absence of residual materials. Again, impacts will rise dramatically if land used must be newly cleared rather than diverted from related cultivation, particularly land which was previously considered marginal because of steep slopes or shallow, easily erodible soil.

Agricultural activities presently affect water resources to a significant degree; indeed, water impact is the most salient area of concern. The pollutants resulting from agricultural discharge include sediments, salt loads, nutrients, pesticides, organic loads, and pathogens. Sediment resulting from soil erosion is regarded as the largest pollutant that affects water quality, cropland being responsible for about 50 percent of the total sediment yield in inland waterways.[41/] The composition of the sediment averages 0.1 percent nitrogen (N), 0.8 percent phosphorus (P), and 1.25 percent potassium (K).[42/] The loss of nitrogen and phosphorus to waterways is approximately 2 pounds of N and 1.6 pounds of P per ton (0.9 Kg of N and 0.7 Kg of P per ton) of sediment. Thus, erosion is also an important factor in loss of soil nutrients.

There are three modes of transport of pollutants from agricultural sources to water: (1) by runoff to surface water, (2) by infiltration and percolation to subsurface waters, and (3) by wind to surface waters. The mechanisms of nutrient transport and deposition in waterways have been investigated under several local conditions and are basically known. However, a knowledge of these mechanisms is not adequate to determine the extent of nutrient losses from individual sources such as fertilizers and livestock wastes, or how these losses may be affected by soil and land characteristics and management systems. Only inferences can be drawn on the extent of nutrient losses and subsequent impacts originating from a biomass farm or silvicultural plantation.

In forest management, skid lanes and logging and fire roads are conceded to be one of the principal sources of soil sediments from forestlands. Logging roads ordinarily are constructed prior to the logging operation, providing access for equipment and serving as routes for timber transport. Skid lanes are the disturbances created by hauling logs from the freshly cut areas to yarding locations or roads. The mineral soil surfaces of these roads and trails are exposed and compacted and have little capacity to absorb runoff during storm events. Such runoff not only causes erosion on the road surface, but also initiates erosion in less disturbed areas. The subsequent major water pollutants originating from forestland sediment runoff are organic matter, applied forest chemicals (pesticides, fertilizers, fire retardants), plant nutrients, and bacteria.

Thermal water pollution from solar radiation can also result from silvicultural activities. Although deviations from "normal" temperatures in surface waters are considered pollutive, thermal pollution involves only the elevation of temperature above a norm. Thermal pollution in forests results from the removal of tree cover which protects streams from solar insolation. As a consequence of direct sunlight exposure, surface water temperatures may become substantially higher in previously protected water bodies.[40/]

An additional, potential water-related concern in large-scale production of biomass is the possible use of irrigation to sustain growth. Large-scale irrigation needs may significantly strain already scarce resources while intensifying irrigation-related problems, such as groundwater contamination. Irrigation return flows contain heavy loads of pesticide and nutrient runoffs, and these contribute to salinity contents of native groundwater. In general, since trees are hardier and less likely to need irrigation than crops, irrigation impacts will be likeliest for crop production in a biomass plantation scheme.

c. Effects on Land Use

Large-scale energy farming is likely to have profound effects on land use patterns in the U.S. Utilizing land already under cultivation for crops or trees (which would produce minimal incremental environmental impacts) would reduce land availability for food and fiber production, causing potentially far-reaching social and economic impacts. If existing crop and forestlands are unavailable, biomass plantations may be located on land which is currently considered of marginal value for farming or timber growth. However, once land -- even marginal land -- is shown to be productive, its capability for producing food or fiber is automatically demonstrated, thus initiating potential competition with food and fiber land resources.

Land use needs for biomass plantations were discussed earlier in the technology section. Depending on land quality, climate, and species, plantation requirements would be in the range of 12,000 to 30,000 acres (4,900 to 12,200 hectares) for forest growth and between 4,000 and 8,000 acres (1,600 and 3,200 hectares) for crop growth.* This acreage is needed to sustain a yield of 250,000 dry tons (225,000 metric tons) annually, viewed as a practical and economic level of supply.

d. Effects on Solid Waste

Solid waste impacts of biomass farming should be minimal, as optimum use of the total yield is a prime goal of the biomass technologies.

e. Effects on Ecosystems

(1) Aquatic Life

Potential impacts on aquatic ecosystems include increased sedimentation and pesticide concentrations. Nutrient runoff from farming or logging operations will contribute to undesirable growth of aquatic plants and subsequent accelerated eutrophication. The magnitude and severity of potential impacts cannot be predicted at this time; however, given the potential scale of the operations involved, significant adverse impacts may occur in at least some locations.

(2) Terrestrial Life

Clearing additional land for biomass production will potentially create a significant change of terrestrial habitat. The magnitude and severity of local impacts will vary with species types, diversity, productivity, and uniqueness, with maximum impacts occuring in areas that were previously undisturbed. In addition to site-specific impacts, the amount of land needed for significant biomass production may also substantially decrease remaining natural land resources on a regional or nationwide basis.

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*Crop growth of 30 dry tons/acre (67 metric tons/hectare); estimates based on one or 2 harvests per year, forest acreage based on Ref. 5.

f. Effects on Esthetics

Biomass plantation activities which produce fugitive dust, erosion, river sedimentation, eutrophication, or large-scale new clearing will adversely affect the visual quality of existing landscapes. This effect will be least severe in areas which are already used for food and/or fiber production.

If silvicultural activities are instigated, visual impacts may be beneficial, especially if marginal lands are used. However, such beneficial visual impacts will be minimal since short rotation schemes for tree growth will be used, preventing maturity of the trees. In this respect, the silvicultural energy plantation will not resemble a natural standing forest.

Historic sites are protected by law from disturbance in the course of Federal and, in many cases, State actions. Private development of land for biomass production, however, might encroach on historic or cultural properties. In addition, changes in general land use patterns and trends may reduce land availability for recreational use in some areas.

2. Impacts of Marine Biomass Cultivation

Proposed maricultural systems under a biomass energy program would grow various species of large kelps (brown algae) attached to floating grids of polypropylene lines with wooden or concrete frames anchored to the ocean bottom. The impacts of structures include not only direct marine environmental effects but, because of the large size of the installations involved, potential onshore secondary impacts related to resource supply, construction, and transportation of harvested materials. Specific potential impacts of marine energy farming are contained in the following sections.

a. Effects on Air Quality

(1) Effects of Construction

Construction and fabrication of marine farm equipment will provide one-time sources of potential air quality impacts. Installment of open-ocean arrays for attachment of kelp is not likely to produce significant air pollution; any such impacts will originate from support vessels' emissions. However, onshore production and transport of raft components may involve greater air impacts, particularly in relation to the manufacture of marine cement and polypropylene lines. Other phases of raft fabrication and transport activities may result in additional emissions of particulates and other pollutants associated with vehicle exhausts, energy production, and various support activities. Nevertheless, the magnitude of impacts associated with construction of marine farming systems should be substantially lower than that associated with terrestrial farming systems.

(2) Effects of Operation

Direct air quality impacts of maricultural activities are likely to be negligible and similar to those arising from existing kelp harvesting practices. Air pollutant emission sources will be the kelp harvesting ships and transport vessels. Most processing (e.g., drying, pressing) will probably take place on shore, and emissions associated with these activities are dependent on the type and quantity of the fuel used and the degree of pollution control employed.

b. Effects on Water Quality

(1) Effects of Construction

Anchoring large arrays and floating frames may create local turbidity as the ocean floor is disturbed during mooring activities. This turbidity will not produce significant impacts and will subside over time. Discharges of fuel or oil wastes from marine vessels and heavy equipment used in deployment present potential local water quality impacts which are avoidable with proper operating procedures.

The greatest water quality impacts from construction will probably originate from construction of onshore processing facilities. Disruption of soil cover and subsequent erosion cause water impacts from these activities. At this time, however, the measure of onshore support industries for kelp processing and conversion is not well-defined.

(2) Effects of Operation

The major water quality impacts from operation will stem from methods of nutrient addition to water at the farm site. Direct nutrient addition, if used, will involve leachate devices to dispense such substances as urea. Deep water upwelling will introduce cooler, nutrient-rich waters from subsurface levels. Surface effects associated with upwelling will be temperature drops, enhanced nutrient concentrations, lower salinity, and introduction or organisms from deeper levels. However, it is difficult to class these effects as adverse or beneficial; moreover, dilutive action and nutrient uptake by plants may counter upwelling-induced changes in the concentration levels of surface waters.

Operational water use at onshore support facilities may impact terrestrial water quality. Such use will include process waste discharges, runoff from disposal areas, and related impacts from possible anaerobic digestion of kelp.

c. Effects on Land Use/Solid Waste

Marine biomass operations will directly affect the use of open-ocean areas. Barges, rafts, and kelp may cover substantial ocean area [up to 1,000 square miles (2,600 Km^2)], so that care must be taken to avoid interference with shipping and fishing traffic. Proposed energy farm plans to date have recognized this problem and usually have sought open-ocean areas away from normal traffic. However, grazer activity near the farm site may shift fishing patterns slightly.

As mentioned earlier, marine biomass installations may affect onshore land use patterns through the need for staging and support facilities. In addition to this direct impact on local land use, there is also the potential for secondary "boom town" growth in sparsely-populated coastal areas, particularly if the biomass fuel produced is to be processed and used in the immediate area. Such growth may affect housing patterns, employment, and various community social services. However, major impacts in this area would require large-scale implementation of maricultural systems which is not expected in the near future.

Solid waste impacts will depend upon application of the harvested kelp. If used for food, little solid waste will be generated. If synthetic fuels are to be derived, some solid waste in the form of unconverted sludge may result. At the same time, both applications may be practiced by deriving a food from the residual of a synthetic fuel process. In this case, anaerobic digestion is the likely conversion technology, resulting in waste sludge (see "Environmental Impacts of Bioconversion"). Generally, solid waste impacts are capable of being averted through use of available options for disposal of kelp residue after conversion. These include uses as food, fertilizer, and source for other chemical feedstocks.

d. Effects on Ecosystems

(1) Effects of Construction

Placement of marine farming rafts may cause some short-term impacts on marine ecosystems. Anchoring mooring lines on the ocean floor may disrupt bottom habitats in the immediate area. The resulting increased turbidity may temporarily disturb some species. However, these impacts will likely be minimal as substantial undersea construction is not anticipated.

For terrestrial habitats, construction of onshore support facilities may impact local ecosystems. Increased stream sedimentation and turbidity may have adverse effects on sensitive species, although this impact may vary by region, since coastal streams in some areas are naturally quite turbid and local aquatic populations are suited to such conditions.

Clearing land to construct biomass support facilities will eliminate local terrestrial habitats. The impact of such habitat loss will depend on the productivity and uniqueness of the habitats, species present, and the land area affected. The potential for adverse effects is particularly high for undisturbed and highly sensitive natural ecosystems which are characteristic of coastal zones.

(2) Effects of Operation

The major ecosystem impacts from operation will stem from the possible use of deep water upwelling for nutrient level enhancement in the open-ocean farm areas. This artificial mixing of natural thermoclines, salinity gradients, and biotic species from upwelling of waters 500 feet (150 m) or more in depth may affect local marine ecosystems. Temperature and salinity represent two of the important limiting factors in the sea. Organisms of the open ocean are usually stenohaline (i.e., have narrow limits of tolerance to changes in salinity), salinity concentrations being partly affected by temperature of the water.

Thus, varied impacts are likely. On the one hand, cooler upwelled water will have a lower salinity content, thereby promoting migration of certain stenohaline species from the areas affected. On the other hand, upwelled nutrient-rich waters may encourage migration of phytoplankton. Only in a few places of vigorous upwelling are nutrients so abundant that phytoplankton cannot exhaust them.[43/] These population shifts therefore may cancel out benefits gained from upwelling, though such conclusions are speculative at best, considering the current state of technology of marine biomass cultivation.

Overall, the consequences of employing upwelled water merits further study. Depending upon the scale of deployment, marine farming could impinge on existing ecosystem patterns to a significant, localized extent.

e. Effects on Esthetics

Construction of marine biomass raft components and onshore support facilities may cause visual disruption of landscapes, fugitive dust, and noise. Because a marine biomass farm will be placed in open-ocean areas not normally visible from shore, esthetic impacts from operation will be minimal.

3. Impacts from Use of Agricultural and Forest Residues

The residues considered in this assessment are those of agriculture (crop), silviculture (logging activities),* and collectible animal manures. Crop residues include those materials, such as rice straw, that are normally collected and disposed of, as well as others such as grain straws, corn stalks, or rootcrop tops which are either purposely left on the field or gathered for use as livestock feed. Forest residues include tree branches, bark, and scrub trees remaining onsite after logging operations. Pulp and mill residues are not considered in this environmental section, since their primary impact is associated with the logging operations from whence they originate. Finally, manures principally considered are those associated with confined feedlot operations (e.g., cattle, dairy, etc.).

Because residues would be created regardless of their subsequent use as biomass fuels, environmental impacts from this source do not include the total effects of the original agricultural and logging activities. Crucial impacts are related instead to the effects of diverting residues from their usual uses and to the effects of direct combustion or conversion to fuel through biomass technologies whose impacts are discussed in the conversion impact sections.

a. Effects on Air Quality

Crop residues remaining on open farmland play a major role in shielding soil from wind action and preserving moisture content. Their removal increases the potential for airborne dust emissions. Airborne dust effects on farming operations include decreased visibility, damage to crops and machinery, respiratory irritation, and general grime. Impacts are of greater concern if such airborne dust contains residues of pesticides or herbicides, as can be the case with some agricultural sources. Crop residues normally left in the field also contribute to the organic content of the soil and increase its internal binding ability. Fugitive dust potential would be further increased if total residue removal continued for several growing seasons, progressively reducing the binding organic content of the soils.

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* In the Fuels From Biomass program, only those residues generated in logging areas are considered. Residues generated at woodmill sites are considered in the ERDA Conservation Program.

At worst, removal of crop residues could contribute to "Dust Bowl" conditions such as those experienced in the Great Plains during the 1930's and to a lesser extent during subsequent droughts. Other susceptible areas include the Columbia River Basin, the Coachella Basin of California, the Connecticut Valley of New England, and many intensely cultivated areas of the Atlantic Coastal Plain.

Mitigation of potential fugitive dust emissions would involve those activities that shield the soil and/or preserve its organic content. Partial removal of residue quantities is one possibility, though the percent that can be safely removed has not been determined. Principally, the use of no-till farming in conjunction with total crop removal schemes would cause less fugitive dust than under till-farming conditions. No-till farming leaves the soil undisturbed for several seasons and harvests only the above-ground portion of the crop; discing for seedbed preparation is not employed. This method preserves root structures and retains much organic content in the soil, thus not disturbing its binding structure. Finally, fugitive dust emissions are greatly dependent on natural factors such as precipitation, soil type, and wind conditions. In this regard, determination of such site-dependent factors would be necessary to determine the optimum management procedures for each area considered.[44/]

Forestlands will be generally less susceptible than croplands to high levels of fugitive dust due to residue removal. However, significant wind erosion could occur in areas that have been clear-cut as opposed to those where immature trees remain to hold the soil and break the wind. Furthermore, removal of forest residues may have a positive air quality impact by greatly reducing the severity of forest fires, which are a significant source of air pollution. Forest fires originating in logging waste average more than 7 times the frequency and severity of other fires.[41/] Removal of logging residues would fulfill a major fire prevention goal and could reduce the degree of air quality degradation fires cause.

In a similar way, the use of crop residues that are normally open-field burned would also lessen such air quality impacts. Biomass conversion of the residue, whether burned or chemically converted, would take place under controlled conditions whereby pollutant emissions would be limited.

b. Effects on Water Quality

Residue removal will increase soil erosion potential by those same mechanisms that contribute to the potential for fugitive dust. A consequence of soil erosion will be increased sediment loads in local watersheds. The severity of this impact will be dependent on soil type, slope of area, precipitation, and degree of exposure.

The impact on water quality from collection of logging residue may vary. The removal of small residuals may benefit water quality since small branches and bark usually find their way into local streams, clogging them. However, if increased residue use results in opening of more logging roads or skid lanes, erosion sources will increase in number. The type of logging practice employed also will affect erosion potential; overall, residue removal in clear-cut areas will result in greater erosion than in selectively cut areas.

c. Effects on Land Use/Solid Waste

The utilization of biomass residue as a fuel source has the advantage of not requiring commitment of additional lands beyond those already used for biomass production. Hence, land use and solid waste impacts are limited to the effects residue removal has on the land.

Positive impacts will include better forest management, reduced fire potential, and less of the solid waste impacts traditionally associated with agricultural crops such as rice straw. Removal of residues may also aid in the development of future crops in cases where thick or heavy residue layers interfere with seedling growth.

Potential adverse effects on future land use as a result of biomass residue removal include water and wind erosion, as previously discussed. Heavy erosion can impair the ability of land to support future crops, woodlands, or other development significantly, thus lowering its value. The adverse effects of residue removal are potentially more acute in farming, since various crop residues may contain from 15 to 200 pounds (7 to 91 Kg) of nitrogen per ton.

Consequently, the degree of residue removal will determine ultimate ecosystem impact. Overall, well-managed crop and forest residue collection schemes may avoid severe adverse effects on local ecosystems. In particular, residue collection in forests may contribute to increased land management practices of a beneficial nature, thus reducing residue clogging of watercourses which does not occur naturally on a large scale in standing forests.

d. Effects on Ecosystems

(1) Aquatic Life

As discussed above, removal of crop and forest residues may contribute significant amounts of sediment to surface waters. Adverse effects of heavy sediment loads include siltation of bottom habitats (used for feeding or reproduction), increased turbidity, and interference with respiration or other physiological needs of aquatic life. Heavy sedimentation of aquatic habitats tends to decrease population diversity and favor rough or forage fish species over game fish such as trout, which prefer clear water. The relative impact of this increase will depend in part upon the amount of sediment directly attributable to residue removal as opposed to other sources, existing turbidity and sediment deposits, the size of the water body affected, and the types of aquatic species present. Maximum impacts would be expected from large sediment loads reaching small, clear, relatively undisturbed streams with sensitive aquatic populations.

(2) Terrestrial Life

The presence of crop and forest residues implies that natural ecosystems have already been greatly disturbed, either through logging of woodlands or replacement by cultivated crops and managed forests. Major impacts affecting the ecology of subsequent crops and woodlands, such as soil erosion, ground cover for seedlings, microbial activity, and fire prevention, have been discussed in previous subsections. The impact of these processes, however, may go beyond the fields or timberlands where they originate and affect the ecology of nearby natural and cultivated lands. For example, fires starting in forest residues may spread over adjacent areas. Similarly, severe soil erosion may cause dust storms capable of producing damage to vegetation over widely distributed locales.

e. Impact on Esthetic Factors

Major potential esthetic impacts of forest and crop residue use are erosion and fugitive dust, conditions which should be avoidable through careful planning and procedures. As lands affected will be those already in use for crops and forestry, historic, cultural, and recreational values will not be threatened. Noise levels will vary with the collection methods and equipment used, but should in most cases be less than, or at most equal to, those caused by the original agricultural or logging activities.

B. Impacts of Biomass Conversion Processes

The following sections discuss impacts resulting from the biomass conversion processes documented in Section II-C. The major processes considered are thermochemical conversion, bioconversion -- chiefly, anaerobic digestion -- and direct combustion. Where applicable and informative, impacts from construction have been included.

1. Environmental Impacts of Thermochemical Conversion

All of the biomass thermochemical conversion processes can produce, in differing quantities, tars and oils, gases, and a char residue. In the biomass conversion schemes now under consideration, the primary fuel produced will be either a liquid or gas, while the char (unconverted residue) will be consumed during the reactions or combusted onsite. Marketing or distribution of the char as a fuel product is not anticipated.

Information on the potential environmental impacts that may be expected from biomass thermochemical conversion processes may be drawn from two sources: laboratory investigations using biomass in thermochemical conversion reactions, and analogous coal conversion (liquefaction and gasification) procedures. From laboratory study, the nature of the residuals (gaseous, liquid, and solid) produced during biomass thermochemical conversion may be found; overall, biomass conversion has been investigated primarily in the laboratory and only the nature -- rather than quantity -- of possible pollutants generated is known. For information on large-scale application of thermochemical conversion and residuals associated under such conditions, analysis turns toward coal conversion technologies. In these processes, operational procedures and potential impacts and respective methods for their control may be postulated.

However, comparisons between coal and biomass technologies end on the operational level. Impacts related to coal conversion arise from coal sulfur and ash contents and the nature of coal ash residue. Overall, biomass thermochemical units should generate significantly less pollutants of concern than analogous processes used in coal gasification and liquefaction. This is primarily due to the lower sulfur and ash contents of biomass.* Thus, pollutants arising from sulfur content and those of particulates and ash will be significantly less in biomass thermochemical procedures than in similar coal conversion technologies.

In the following analysis, the various thermochemical processes -- pyrolysis, gasification, and hydrogenation (liquefaction) -- have been treated aggregately. This is possible because, throughout each process, similar pollutants will be encountered although the quantities generated will differ significantly in each case. Thus, gasification will produce a gas as its primary product, though production of some liquid (condensates) and solid (ash) residuals will accompany the reaction; likewise, liquefaction will produce oils as its primary product, while also generating small amounts of gas and ash. However, for cases in which certain residuals are peculiar to a particular process, the distinctions between the impacts of that process and others are noted.

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* The ash content of most biomass is less than one percent. The sulfur content of biomass is more varied, though almost always less than 0.3 percent. The reported sulfur contents of most wood and wood chip residue are usually between 0.1 and 0.08 percent per dry unit (References 45 and 46). Professor Ellis Darley of the University of California at Riverside, Plant Pathology Department, reports that the low range of biomass sulfur content (per most dry plant matter) runs between 0.14 and 0.19 percent, while average sulfur contents run between 0.2 to 0.3 percent. These values compare to coal ash and sulfur contents of between 0.9 to 3.0 percent for sulfur and approximately 10 percent for ash. Furthermore, the natures of coal and biomass ash differ considerably, as is documented in later parts of this section.

Finally, this section considers atmospheric emissions of gaseous and volatile pollutants. While it is beyond the scope of this report to attempt to model ambient concentrations of all pollutants possibly generated, an attempt was made to conduct a preliminary analysis of those pollutants that may be of concern.

a. Effects on Air Quality

(1) Effects of Construction

The construction of a thermochemical unit for biomass conversion should cause no air quality problems beyond those encountered in construction of industrial installations and petrochemical conversion units (e.g., catalytic cracking units, gasification units, etc.).

The problems typically encountered in construction of such installations are those arising from fugitive dust emissions. Such emissions are generated by a wide variety of operations over the duration of construction. These include land clearing, ground excavation, cut and fill operations, and the construction of the facility itself. Dust emissions vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing weather. A large portion of the emissions results from equipment traffic over temporary roads at the construction site.

An estimated high particulate emission factor of 1.4 tons/acre/month has been calculated to represent construction activity in an arid region.[39/] For construction in less arid regions, this figure would likely be lower. The use of various control techniques, either wet or chemical, may reduce these emissions substantially. Watering twice daily can achieve reductions of about 50 percent. Chemical suppressants employed for dust control can achieve an 80 percent control efficiency on completed cuts and fills.[44/]

(2) Effects of Operation[47/]

Air pollutants of a similar nature are generated by all thermochemical processes. Emissions may originate from a process stack, a waste pond, a storage tank, equipment leakage, or from wind erosion of unconsolidated residues or ash piles. Pollutants of concern are sulfur dioxide (SO_2) and trioxide (SO_3), hydrogen sulfide (H_2S), hydrocarbons (HC), ammonia (NH_3), hydrogen cyanide (HCN), nitrogen oxides (NO_x), particulates and, to a lesser extent, carbon monoxide (CO).

This section will consider the nature of these pollutants and their possible effects. While it is beyond the scope of this report to determine the ambient concentrations of all the pollutants resulting from thermochemical conversion, some preliminary analyses into those impacts deemed possibly significant have been carried out.

(a) Direct Emissions from Gasification Units

The "worst-case" for generation of gaseous potential pollutants is the operation of a gasification unit. The atmosphere in a gasifier is charged with an abundance of hydrogen; thus, the primary reactions of sulfur and nitrogen will be with hydrogen and, to some extent, with carbon. These oxidation-reduction reactions produce the following compounds of concern: ammonia (NH_3), hydrogen sulfide (H_2S), hydrogen cyanide (HCN), carbonyl sulfide (COS), and carbon disulfide (CS_2). Because biomass contains some 3 percent nitrogen by weight compared with a coal nitrogen content of 1 to 2 percent, nitrogen-containing by-product gases may be generated on a slightly larger scale than encountered with coal gasification schemes.

Liquefaction and pyrolysis will produce gaseous emissions similar to those from gasification. However, in these processes sulfur- and nitrogen-derived emissions should be less, since much of the residual sulfur will be distributed between the solid (char) and liquid (oil) fractions. For instance, in pyrolysis 50 to 65 percent of the original sulfur and 40 to 60 percent of the original nitrogen remain in the char residue. The fate of this residual sulfur or nitrogen is dependent on what is done with the oil and char: whether it is gasified, combusted onsite, or shipped out as a fuel for use elsewhere.

(i) Ammonia and Hydrogen Cyanide

Ammonia and HCN can be removed in aqueous solution, as in coal gasification procedures, in which removal efficiencies are quite high. Ammonia is a valuable by-product and its recovery can be economically beneficial.

Ammonia is a highly irritating gas with a strong pungent odor. It forms the intensely alkaline ammonium hydroxide when it comes in contact with the moisture of the throat and bronchi. At concentrations of 280 to 490 mg/meter^3 ammonia gas causes slight irritation of the eyes as well as a hoarse voice, but higher concentrations of 1700 to 4500 mg/meter^3 are required to induce pulmonary edema.[48/] Such concentrations would be atypical of normal operation and unlikely to occur offsite under any conditions.

Hydrogen cyanide is an extremely toxic gas when encountered in closed areas or in concentrated form. It is occasionally found in manufactured gas at concentrations of 200 to 300 ppm, but it is rarely injurious in the open atmosphere.[48/] The

Occupational Safety and Health Administration (OSHA) time weighted average (TWA) standard for occupational safety is 10 ppm. The volume of HCN produced in biomass thermochemical conversion and potentially released through leakage or deliberate emission is presently unknown.

(ii) COS and CS_2

Thermochemical processes also will produce trace quantities of COS and CS_2 from sulfur reduction by carbon. For reference, coal gasification schemes presently convert from 1 to 10 percent total sulfur to COS and CS_2. If these products are incinerated, then all organic sulfur components will be converted to SO_2 and CO_2. However, some unconverted COS and CS_2 may leak into the atmosphere through valves and fittings if careful system monitoring is not maintained.

Carbonyl sulfide (COS) is narcotic in high concentrations. Upon decomposition, it liberates hydrogen sulfide (H_2S).[49/]

The toxicity of carbon disulfide (CS_2) has been studied primarily in occupational environments because of its widespread use in the production of synthetic rayon in the 1950's. One study performed with rayon workers in Japan noted that when occupational exposures were between 40 and 50 ppm in the air, significant numbers of workers developed mental disorders, fatigue, and gastritis. To date, no long-term, low-exposure level ambient air studies have been performed to evaluate the effect of CS_2 on susceptible human population segments.[50/]

(iii) H_2S

Hydrogen sulfide is the major sulfur compound produced during gasification (90 to 99 percent of the converted sulfur is in this form). It is also the major sulfur-containing gaseous pollutant produced through other thermochemical reactions. In coal gasification procedures, H_2S emissions are actively controlled by scrubbing with absorption liquors. However, biomass has a much smaller sulfur content than coal -- approximately 20 times less per Btu -- and sulfur-containing pollutants are thus produced in much smaller quantities. Nevertheless, the extreme potency of H_2S allows its odor to be detected in concentrations as low as 0.5 ppb (7 $\mu g/m^3$), requiring very little sulfur in the conversion material to cause discernable effects.[51/] For these reasons, it was felt that some form of preliminary analysis into possible H_2S emissions from a biomass thermochemical plant was warranted.

A modeling effort was therefore carried out based upon the operation of a hypothetical hydrogenation conversion plant.* This particular process was used because the off-gas stream produced during hydrogenation was the likeliest one to be purposely vented uncontrolled to the atmosphere (assuming no adverse environmental impact) due to the gas' low volume and heat content. In gasification, the high-Btu gas produced would be scrubbed and upgraded before use, thus removing any contaminants present. For low-Btu gas produced by pyrolysis, combustion of the gas would probably occur onsite, converting H_2S into SO_2 and water. In each case -- pyrolysis and gasification -- H_2S would not enter the atmosphere purposely from the gas stream; however, this possibility exists for hydrogenation processes. In this respect, hydrogenation was chosen as the basis for the model. Nevertheless, results obtained from the model may be used to simulate worst case conditions encountered in either gasification or pyrolysis in which the raw product gas accidently leaks from the system.

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* The postulated plant was based on the procedures used in the BuMines hydrogenation process (References 20, 21, and 23). Although both liquids and gases are produced in this procedure, attention was focused on the gas stream only for the model used.

The modeling effort was based on a conversion plant designed to process 2000 lbs of dry wood chip waste per day. The gas stream produced by this process was examined in light of H_2S emissions into the atmosphere and resulting ambient concentrations. Processed wood chip residue used for conversion was assumed to have an 0.1 percent sulfur content - the amount used in EPA's "Compilation of Air Pollutant Emission Factors" (Reference 52). For worst case modeling, it was further assumed that the entire sulfur content is converted into H_2S during the thermochemical reactions. Thus, one ton of wood chip waste with a sulfur content of 0.1 percent -- undergoing conversion -- would produce 2.13 pounds per hour (965 mg/hr) of H_2S.

At the above mentioned conversion rate, the H_2S concentration in the raw off-gas stream would be approximately 608 ppm. This concentration is well above the OSHA maximum permissible concentration of 20 ppm for H_2S, and would pose a definite occupational hazard in its raw, undiluted form (see Section III-B-2 for a further discussion of H_2S physiological effects). To determine the resulting downwind ambient concentrations of H_2S, modeling efforts were conducted. Under worst case meteorological conditions, it was estimated that the maximum ambient H_2S concentration would be 398 $\mu g/m^3$ (0.29 ppm) at approximately 0.04 miles (0.063 km) downwind from the source. While this ambient concentration is below the OSHA maximum permissible standard, it remains above the odor threshold of 7 $\mu g/m^3$ (0.5 ppb); furthermore, it was determined that at the farthest point modelled from the source -- 0.37 miles (0.6 km) -- the ambient H_2S concentration was still above the odor threshold at 72.8 $\mu g/m^3$. Thus, venting of raw off-gases to the atmosphere could present an odor problem from H_2S concentrations as well as a possible occupational concern.

For the quantity of H_2S being generated from a thermochemical biomass conversion plant, the easiest method of control is flaring. Flaring the gas would convert all the outgoing H_2S into sulfur dioxide and water. For the hypothetical conversion plant discussed herein, flaring the gas stream containing H_2S would produce a maximum downwind SO_2 concentration of 75 $\mu g/m^3$. Such a concentration is well below the most rigorous State ambient SO_2 standards and should not present any significant environmental impact. In addition to flaring, other control systems could be employed which actively remove H_2S from the product stream. These include the Stretford process, which can attain a final H_2S content of 1 ppm in the treated gas, and the Takahax process, which is particularly suited to those gas streams low in initial H_2S concentrations.[53/]

(iv) Hydrocarbons

In thermochemical processes, low molecular weight gaseous hydrocarbons (aside from methane) will be generated. Atmospheric emissions of these substances may occur from storage tanks, wastewater separation operations, and valve leakage. These emissions may contain polynuclear aromatic compounds and phenols.

- Phenols - Wood wastes consist of cellulose, lignin, hemicellulose, protein, lipids, humic acid, water, and minerals. Lignin is the second major constituent of wood (cellulose is first), comprising up to 30 percent of the total contents. Generally, lignin is composed of a chain of aromatic compounds (a phenylpropane polymer is one form). Lignin hydrogenation leads to the formation of phenols in high yields.[54/] For example, 100 atmospheres of hydrogen at 716°F (380°C) for two hours in the presence of a 2 percent cobalt sulfide catalyst gave a 46 percent yield of phenols from pinewood lignin. As a gas, phenol exhibits toxic qualities.[49/] Chronic poisoning, following prolonged exposures to phenol vapor or mist, results in digestive disturbances such as vomiting, difficulty in swallowing, excessive salivation, diarrhea, loss of appetite, and nervous disorders such as headache, fainting, dizziness, mental disturbances, and skin eruption.

- Polynuclear aromatic compounds (PNA) - Polynuclear aromatic compounds are organic molecules of fused benzene rings. It has been found that many of these compounds are carcinogenic in laboratory experiments. One of the most potent carcinogens in this class is benzo-(a)-pyrene which is known to be present as a coal combustion product, though its presence in the off-gases of cellulosic gasification has not been investigated.

(b) Emissions from Onsite Fuel Combustion

The primary air pollutants from combustion of the liquid and solid fuels produced by the various thermochemical processes are nitrogen oxides (NO_x), fly ash, small quantities of sulfur oxides, (SO_x), and various trace metals which may vaporize and become gaseous pollutants (e.g., mercury, beryllium, arsenic compounds, or fluorides). Other trace metals such as nickel, zinc, cadmium, and molybdenum will exist in fly ash as particles rather than vapor. The generation of air pollutants from raw biomass (wood) is more fully discussed in Section III-B-3.

If gas is burned, it is assumed that particulates, sulfur compounds, and trace metals will not be problems; rather, only nitrogen oxides will be, formed by reactions of nitrogen and oxygen (in the air) at high temperatures [over 2000°F (1090°C)]. In combustion of low-Btu producer gas, little nitrogen oxide formation should occur due to the relatively low temperature achieved during combustion of the gas.

For the secondary fuels, the primary concerns are those of sulfur content and subsequent emissions from combustion. Table III-1 estimates sulfur dioxide emissions from biomass-derived fuels and compares them to EPA New Source emission standards for coal, oil, and gas. Because of the inherent low sulfur content of biomass and biomass-derived fuels, there is little problem in the area of sulfur oxide emissions.

For trace metals, emissions will depend upon their concentration in the char, which is dependent on the original biomass material. The degree of these emissions from biomass conversion processes is not known at this time; however, their content in raw biomass materials is known (see Table III-2).

(c) Feedstock Storage/Odor

Storage of raw biomass material may present problems of odor at a conversion facility especially if anaerobic decay conditions are allowed to occur. Wet crop residue or manures could be problematic in this regard. Wood waste, because of its resistance to decay, should pose the least difficulty.

b. Effects on Water Quality

(1) Effects of Construction

The construction of a thermochemical facility requires disruption of soil cover, thus increasing sediment loads to local watersheds. Uncontrolled sediment load wash to surface waters is increased 20-fold as compared to grassland and 100-fold compared to forested land.

Typically, this sediment load varies between 5 and 50 tons per acre-year (11 to 110 metric tons/hectare-year). However,

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TABLE III-1

ESTIMATES OF SOME EMISSION FACTORS FROM COMBUSTION OF BIOMASS FUELS AS COMPARED TO NEW SOURCE PERFORMANCE STANDARDS

FUEL	HEATING VALUE	%S	lb SO_2/MMBtu (Kg SO_2/10^9cal)
Char	7,290 Btu/lb (2,240 Kcal/Kg)	0.3	0.823 (1.484)
Oil (Biomass)*	120,000 Btu/gal (8,000 Kcal/1)	0.11-0.3	0.14-0.49 (0.25-0.88)
Producer Gas	140 Btu/ft^3 (1,000 cal/m^3)	—	Unknown

EPA NEW SOURCE PERFORMANCE STANDARDS[a/]

FUEL	HEATING VALUE	ALLOWED SO_2 EMISSIONS IN lbs /MMBtu (Kg/10^9 cal)
Coal	~10,500 Btu/lb (5,820 Kcal/Kg)	1.2 (2.2)
Oil (#5)	144,500 Btu/gal (9,600 Kcal/1)	0.8 (1.4)
Natural Gas	~1,000 Btu/ft^3 (7,150 cal/m^3)	—

* See Table II-4.

a/ Source: Compilation of Air Pollution Emission Factors, Reference 54.

TABLE III-2
TRACE ELEMENTS OF COAL AND BIOMASS

ELEMENT	CONCENTRATION[a] IN RAW COAL (ppm)	PORTION EMITTED DURING COAL GASIFICATION PROCESS[a] (%)	CONCENTRATION IN BIOMASS (ppm)[b]
Antimony	0.15	33	0.06
Arsenic	9.6	65	0.2
Beryllium	0.92	18	<0.1
Cadmium	0.78	62	0.64
Chromium	15	0	0.23
Lead	5.9	63	2.7
Mercury	0.27	96	0.015
Nickel	12	24	2.7
Selenium	1.7	74	0.2
Tellurium	0.11	64	—
Vanadium	33	30	1.6

a/ Data are for the HYGAS process using Pittsburg No. 8 coal.

Source: A. Attari, "Fate of Trace Constituents of Coal During Gasification," EPA-650/2-73-004, Environmental Protection Agency, Research Triangle Park, North Carolina, August, 1973.

b/ Data based on angiosperm concentration.

Source: H.J.M. Bowen, Trace Elements in Biochemistry, Academic Press, London and New York, 1966, Ref. 55.

rates of sedimentation are highly dependent on rainfall characteristics, topography, and soil type. The areas of water quality concern produced by sedimentation are those of suspended solids and turbidity. Generally, suspended solids consist of two main classes: inorganic (nonvolatile) and organic (volatile). The former class arises from erosion of high clay content soils. Upon runoff to surface water, the small clay particles remain in suspension, causing a turbid or cloudy water condition. Organic solids are of concern because they may harbor potentially pollutive micro-organisms, although they degrade over time.

Total suspended solids reach levels of concern at around 80 ppm, and short-term levels of a few thousand ppm may exert harmful effects on local fish populations. These conditions may result from severe erosion through heavy but infrequent rainstorms in the region. Generally, erosion and sedimentation are proportional to the land area cleared. In this regard, the least harmful effects are associated with the smaller units.

(2) Effects of Operation

Water is involved in the thermochemical systems in two capacities. In the first, water results from the decomposition of cellulose in the biomass. Water produced this way will generally be collected as a condensate. In the second case, water is used as a chemical reactant. This use is isolated to the liquefaction process, where water is used in wood slurries fed to the unit, as well as in the actual chemical process. In both cases, many of the compounds previously discussed (e.g., HCN, NH_3, H_2S, phenols) will be present in the process or waste waters.

The fate of these wastewaters is uncertain, though it is likely, especially in the latter situation, that they will undergo similar treatment processes employed in solvent refined coal procedures. In these, oils are removed from the aqueous process stream to be used for recycling. Remaining water is further treated to be finally discharged (in a form meeting water quality criteria) to a lagoon or waterway.

Besides effluents that can affect water quality, thermochemical conversion will generate ash residues which may eventually impact water quality. These ash residues will likely be disposed of in a pit where leaching of pollutants to the groundwater may occur. However, thermochemical conversion of biomass will generate less ash than that encountered from coal gasification or liquefaction (wood has less than 1 percent ash; coal has 10-12 percent ash).

(a) Major Pollutants

The water pollutants evolved from biomass conversion have been studied little, and in general most examples are taken from coal conversion technologies. While coal conversion is the closest analog, it represents a worst case situation for the case of ash disposal because of coal ash's high mineral content. Pollutants likely to be present in coal conversion wastewaters include compounds of ammonia, cyanide, phenols, and trace elements. Of these pollutants, trace metals from ash are not likely to be contained in biomass conversion wastewaters (to appreciable extents).

(i) Ammonia

Ammonia is a gaseous alkaline compound that is highly water soluble. Although normally present in most water as a degradation product of nitrogenous organic matter, NH_3 may also reach ground and surface waters through effluents from gasification and liquefaction. Ammonia reacts with water in the following fashion:

$$\underset{\text{Ammonia}}{NH_3 + H_2O} \longleftrightarrow \underset{\text{ionized form}}{NH_4^+ + OH^-} \longleftrightarrow \underset{\text{ammonium hydroxide}}{NH_4OH}$$

Ammonia in its ionized form is usually nontoxic to aquatic life; yet, greater alkalinity (higher OH^- concentration) will drive the reaction to the left, increasing the proportion of non-ionized ammonia which is toxic. [56/]

The generally accepted range of lethal (to fish) concentrations of NH_3 in water is 0.2 mg/liter. Concentrations below 0.2 mg/liter may not kill significant numbers of fish, but may produce adverse effects.[56/]

(ii) Cyanide (CN^-)

HCN is a gaseous compound, soluble in water to some extent. It is also a weak acid, ionizing according to the following equation:

$$HCN \longleftrightarrow H^+ + CN^-$$

HCN is probably the most toxic form of CN in water. However, because of pH variability, cyanide safety can only be measured by the total ions (CN^-) in water. A maximum concentration of 200 mg/liter for domestic water supplies provides a reasonable margin of safety. [56/]

(iii) Phenols

Adverse ecological effects from phenols may occur in the following ways: (1) direct toxicity to fish, reducing available dissolved oxygen in the water due to their high oxygen demand, and (2) by the tainting of fish flesh.

The nature of the chemical reactions which phenols might undergo in an evaporation pond is not known, nor is the lifetime known of those compounds in a pond.[56/]

(b) Trace Elements

Certain fractions of the inorganic ash are volatile: most mercury (Hg), arsenic (As), and selenium (Se) compounds boil below 1,200°F (649°C) at atmospheric pressure. Thus, almost all of the thermochemical processes will have these compounds present in vapor form in the product gas stream. These compounds will later condense out into the aqueous condensate or washes where they will eventually be channeled to a disposal pond.

Table III-2 presented concentrations of some trace metals found in biomass and raw coal.* The percentage of these compounds emitted during the HYGAS coal gasification process is also given. Because biomass has low concentrations by comparison, the magnitude of toxic elements disposed of will be much less than in coal gasification schemes. However, the degree to which these pollutants may accumulate before exerting harmful effects is not well documented.

(c) Feedstock Storage

Wood chips-in-oil and wood chips-in-water slurries, manure, wood, and various biomass feeds used in thermochemical conversion all offer potential water quality problems through leachates from storage piles. However, leachates from biomass piles will not contain any bioexotic compounds, nor toxic elements to the degree that coal pile leachates do.

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* See also Table III-8.

c. Effects on Land Use

(1) Effects of Construction

Land use characteristics for biomass conversion units can only be paralleled with those encountered with coal conversion systems. For coal gasification, it has been reported that the El Paso Lurgi gasification site in New Mexico will occupy about 960 acres (389 hectares) for 30 units, equalling about 32 acres (13 hectares) per unit.[47] This is for the entire plant facility, excluding the ash disposal site, which in this case will be at the mine. For wood ash disposal, a pit will probably be used. The normal requirement for such a pit is a cubic foot for every 50 pounds (23 Kg) of ash.

The Lurgi site also includes 100 acres (40 hectares) to be used as a lined waste pond and 10 acres (4 hectares) for coal storage and a gas-fired electric power plant. There is some doubt in assuming that a cellulosic waste gasification plant will require more than 32 acres (13 hectares) per unit; indeed, the Lurgi plant is larger than other proposed coal gasification plants and will be capable of handling 25,000 tons (23,000 metric tons) of coal per day. Liquefaction and pyrolysis will both have land needs similar to the gasification plant; however, considerably greater storage areas for liquid and solid residue will be required.

The biomass low-Btu gas pyrolysis units will require much less land area, perhaps occupying some 1.5 acres (0.6 hectares) for a 20 ton/day (18 metric tons/day) plant.

(2) Effects of Operation

Operation will require, in addition to the facility site area, land for ash disposal. For a gasification, liquefaction, or pyrolysis unit converting 1,000 tons/day (900 metric tons/day) biomass with a 1 percent ash content, approximately an 0.32-acre (0.13-hectare) ash pit of 10-foot (3 m) depth will be required per year, assuming all char is combusted.

Temporary storage areas for liquid and char products will also be required, their size depending on how long they will be kept (see discussion on solid waste).

d. Effects on Solid Waste

(1) Effects of Construction

The source of solid waste produced in construction will be the clearing of vegetation, resulting in significant quantities if 32 acres (13 hectares) are needed. This cleared vegetation will likely be restricted to weeds, grasses, and trees, and because much of this material may be suitable for conversion, large-scale disposal problems may be avoided after unit start-up. Thus, the effect from clearing vegetation at a biomass conversion facility on solid waste should be less significant than that resulting from construction of an industrial site.

(2) Effects of Operation

Liquefaction, gasification, and pyrolysis units will all produce chars which may be combusted leaving ash. The disposal of ash has been discussed previously.

If chars are not immediately combusted, storage will be required. In pyrolysis, some 726 pounds of char may be produced per ton of feed (364 Kg/metric ton), while in hydrogenation (to oil) approximately 1,000 pounds may be produced per ton (500 Kg/metric ton).16/20/ Hydrogenation, therefore, represents the worst case. For a 1,000 ton/day (900 metric ton/day) hydro-

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genation plant, approximately 500 tons (450 metric tons) of char will be produced daily. Storing a one-week supply of char in 10-foot (3 m) piles will utilize a land area of 0.64 acres (0.26 hectares), assuming a char density of 25 pounds per cubic foot (401 Kg/m^3).

There are two possible forms of char: one that results from incomplete carbonization (brown char), and one that is formed from complete carbonization (black char). Carbonization is a largely irreversible chemical change occurring when oxygen, hydrogen, and nitrogen are driven off, leaving carbon. Of the two forms, black char is the most stable and may even be stored outside (in reasonable quantities) for up to a year while not producing any appreciable leachate. Though black char will produce a leachate under certain circumstances, the leachate of brown char offers a greater potential for environmental hazard. The standard water pollution tests indicate that brown char leachate has a 5-10 times greater pollution potential than black char leachate (see Table III-3).

The production of hazardous residues from operation of thermochemical units is also of concern. The tars produced by thermochemical decomposition of organic substances, especially the action of destructive distillation, have superficial resemblance to coal tars. This is a possible area of concern since coal tars are known to contain carcinogenic compounds, in particular, the polynuclear aromatics (PNA).

The operator of a pyrolysis or other conversion unit may come in contact with tars in the handling of equipment. A preliminary investigation conducted at the department of pathology at Cornell University studied the tars produced by the destructive distillation of chicken waste.[57/] "Swiss" type mice were used to determine if the tars and chars of pyrolysis

TABLE III-3
LEACHING TESTS

CHARS WERE SOAKED IN DISTILLED WATER FOR 24 TO 28 HOURS.

CHARACTERISTIC	BROWN CHAR LEACHATE	BLACK CHAR LEACHATE
Clarity	clear	clear
Color: Turner, 580 nm	30%-80%-transmission	97%-100% transmission
pH	7.3-7.4	9.9-10.6
COD	20,000-31,000 mg/l	625-650 mg/l
TKN	2,400-15.000 mg/l	70-78 mg/l
Total Solids	Dry -1.71%-3.4%	2.1%-2.22%
	Ash -0.83%-2.45%	1.56%-2.2%
$N\text{-}NH_3$	900 mg/l	16.3 mg/l
BOD	22,000 mg/l	160 mg/l

CHARS WERE LEACHED BY A FLOW OF DISTILLED WATER THROUGH THE CHAR.

CHARACTERISTIC	BROWN CHAR LEACHATE	BLACK CHAR LEACHATE
Clarity	Not clear (foam on surface)	clear
Color: Turner, 890 nm	70% transmission	100% transmission
pH	7.8	8.6
COD	650 mg/l	85 mg/l
TKN	50 mg/l	5 mg/l
Total Solids	Dry -0.11%	0.17%
	Ash -0.06%	0.14%
$N\text{-}NH_3$	18 mg/l	none
BOD	260 mg/l	45 mg/l

Source: "Conservation of Energy and Mineral Resources in Wastes Through Pyrolysis," Ref. 57.

would develop any carcinomas. After 210 days, mice exposed to char or tar were free of any problem. However, all mice of a control group treated with 3,4-benzo-(a)-pyrene (a known carcinogen) developed carcinomas in 90 days.

Though this study indicates that tars produced by pyrolysis of chicken waste may offer no hazardous residue problem, this area remains open to investigation in relation to all biomass materials.

2. Environmental Impacts of Bioconversion

Anaerobic digestion, which produces methane, and alcohol fermentation, which produces ethanol, essentially have similar environmental problems: both systems employ micro-organisms in an aqueous medium and both generate a waste sludge which must be disposed. The waste mixture includes a solution of dissolved pollutants and an undissolved portion of inorganic and organic solids. This waste mixture, or sludge, may be disposed of in its entirety or separated into solid and aqueous components prior to disposal. Nevertheless, effluents from either procedure (anaerobic digestion or alcohol fermentation) require similar treatment and result in similar environmental impacts.

Anaerobic digestion currently is used on a wide scale in treatment of municipal wastewater. The goal of this application is the breakdown of organic solids present in the waste; methane production is of secondary concern. However, anaerobic digestion is easily transformed into a technology of energy production, and investigation of its methane-producing capabilities is being done on a significant scale. Alcohol fermentation as an energy production technology remains in the experimental stage. Thus, the focus of this section is on anaerobic digestion for three reasons: (1) anaerobic digestion systems using animal waste are in use and have been studied; (2) this is to be the technology (of the two) having the widest application in the near term; and (3) the environmental impacts can be specifically illustrated using anaerobic digestion of animal waste. Similar circumstances do not apply to alcohol fermentation of biomass.

The following discussion on environmental impacts is divided into two sections. The first examines possible environmental impacts associated with anaerobic digestion of animal waste, as discussed in the technology section. Water quality is the primary area of concern, since it may be affected by digester wastewaters. The second section outlines present waste management practices suitable for application to anaerobic treatment of biomass. The focus of the second section is on land disposal of treated sludge, its problems, and benefits.

a. Environmental Impacts of an Anaerobic Digester Using Cattle Waste

(1) System Design

The Agricultural Research Service is presently designing an experimental facility at Clay Center, Nebraska, to evaluate the anaerobic digestion process of animal waste. The plant will consist of a 1,230-gallon (4,660 l) fermenter designed to handle on a daily basis 350 to 400 pounds (160 to 180 Kg) of manure, roughly that of 10 to 12 beef cattle. The load capacity per day will consist of 100 pounds (45 Kg) dry matter and 900 pounds (410 Kg) water to be fed as a slurry to the 1,230-gallon (4,660-l) digester. This will be a continuous feed process where the 10 percent solids-containing solution will undergo digestion for approximately 10 days before exiting the digester.*

For discussion purposes, three different digester capacities have been hypothetically constructed, the smallest being based on the Clay Center Digester. The range of capacities is as follows:

- 1,230 gallons (4,660 l); serving approximately 10 beef cattle; 10 percent solids; 10 day SRT; 120 gal/day (455 l/day);
- 12,300 gallons (46,600 l); serving approximately 100 beef cattle; 10 percent solids; 10 day SRT; 1,200 gal/day (4,500 l/day); and
- 123,000 gallons (466,000 l) serving approximately 1,000 beef cattle; 10 percent solids, 10 day SRT; 12,000 gal/day (45,500 l/day).

From data derived from laboratory studies done in conjunction with pilot plant modeling, two operating situations were hypothesized: (1) a high solids content (5.08%) in the digester effluent, and (2) a low solids content (4.80%) in the digester effluent.[27/] Solids content in the effluent indicates relative digester efficiency, assuming most solids are organic. A high solids content represents less biodegradation of original material than with a lower effluent solids content from digestion of the same material. Variation of daily operating procedures, as well as feed material, can result in variations of digester operation. Therefore, the conditions outlined offer a range of digester operations that can be expected at a facility utilizing cattle manure. Tables III-4 and III-5 present the situation of "low solids" and "high solids," respectively.

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* i.e., a solids retention time (SRT) of 10 days.

TABLE III-4
LOW SOLIDS DIGESTER PERFORMANCE

			Influent[a]			Effluent		
			[pounds/day (Kg/day)]			[pounds/day (Kg/day)]		
Number of Cows	Digester Capacity	Daily Water Volume	TS	VS	NVS	TSS	VSS	NVSS
10	1,230 gal (4,660 1)	120 gal (455 1)	100 (45)	80 (36)	20 (9)	41 (19)	21 (10)	20 (9)
100	12,300 (46,600)	1,200 (4,550)	1,000 (450)	800 (360)	200 (90)	410 (190)	210 (100)	200 (90)
1,000	123,000 (466,000)	12,000 (45,500)	10,000 (4,500)	8,000 (3,600)	2,000 (900)	4,100 (1,900)	2,100 (1,000)	2,000 (900)

a/ Based on solids content of 20 percent nonvolatile, 80 percent volatile.

SOURCE: EEA, Inc.

TABLE III-5
"HIGH SOLIDS" DIGESTER PERFORMANCE

			Influent a/			Effluent		
			[pounds/day (kg/day)]			[pounds/day (kg/day)]		
Number of Cows	Digester Capacity	Daily Water Volume	TS	VS	NVS	TSS	VSS	NVSS
10	1,230 gal (4,660 l)	120 (455)	100 (45)	80 (36)	20 (9)	62 (28)	42 (19)	20 (9)
100	12,300 (46,600	1,200 (4,550)	1,000 (450)	800 (360)	200 (90)	620 (280)	420 (190)	200 (90)
1,000	123,000 (466,000)	12,000 (45,500)	10,000 (4,500)	8,000 (3,600)	2,000 (900)	6,200 (2,800)	4,200 (1,900)	2,000 (900)

a/ Based on solids content of 20 percent nonvolatile, 80 percent volatile.

SOURCE: EEA, Inc.

The situations expressed in Tables III-4 and III-5 are based on a feed composition of 20 percent nonvolatile solids (NVS) and 80 percent volatile solids (VS). The effluent compositions are based on suspended solids (SS). In actual practice, anaerobic digester operation may differ from the data expressed in the tables, factors contributing to this difference being load rate, solids content of feed material, type of feed material, influent composition, and others. However, the data expressed herein are sufficient for discussing areas of environmental concern.

(2) Effects on Water Quality

Possible effects on water quality occurring from the anaerobic digestion process concern the disposal method chosen for digester wastewater effluent. Anaerobic fermentation decreases the pollutive content of raw manure, but does not eliminate it. Accordingly, final disposal of effluent -- and whether or not it contacts a water body -- will determine the resulting effects on water quality. Currently, there are a number of disposal methods for digester sludge used in municipal waste treatment [see Section III-B-2(b)]. Any of these processes are available for bioconversion systems. In addition, recycling or partial recycling of effluent back to the digester is also under consideration, although no experimental facilities have actually employed this method. Hindrances to this system are the costs of treatment needed before the wastewater can be recycled. For the hypothetical facilities discussed herein, it is assumed that effluent is disposed of by either irrigation or lagooning. However, this is not meant to preclude recycling if this method proves practical; in light of such a possibility, the following discussion can be taken as a worst case assumption (i.e., total effluent discharge).

For each of the three digester capacities mentioned, discharge into a holding pond or evaporation pond is the probable first step in waste disposal. For both the 1230 (4660) and 12,300 gallon (46,600 l) digesters [120 gal/day (455 l/day) and 1200 gal/day (4550 l/day) effluents, respectively], final disposal into an evaporation pond is likely. This is due to the small capacity for irrigation each of the digester effluents has.

The largest capacity digester, producing a 12,000 (45,500 l) effluent daily, is the likeliest of the three to serve as a practical irrigation supplement. Discharge into a holding pond would be the first step, whereupon portable irrigation equipment would collect the supernatural wastewater to be distributed on the field or grazing land (portable equipment usually carries about 1000 gallons (3790 l). If mechanical dewatering of the sludge is employed to separate solids and liquid, the remaining liquid will be channeled to an evaporation pond and handled in a similar fashion. (Use of solids as feed has been suggested at the Clay Center pilot plant to determine their feed value for ruminants.)

Piping of effluent directly to the field for irrigation would probably not be practical until much larger bioconversion facilities come on line, approaching the one million gallons per day figure. Furthermore, special equipment is required for such operations, precluding introduction of wastewater into existing irrigation facilities. In the bioconversion capacities dealt with here, portable irrigation equipment would be the probable mode of application, if irrigation is the selected disposal method. If irrigation proves economically impractical, other disposal methods will be required, including sludge drying beds, discharge into waterways, and discharge into public works sewage treatment operations.

Table III-6 presents estimates of effluent concentrations based on the two operating conditions of "high" and "low" effluent solids. Assuming uniform feedstock, the high solids content indicates less organic decomposition within the digester than encountered with low solids effluent content. The values given in Table III-6 thus are dependent on breakdown of volatile solids (VS) within the original sludge influent, the degree of breakdown being reflected by the suspended solids (SS) of the effluent.

Inorganic substances also will be present in the digester and its effluent. These substances, termed nonvolatile solids (NVS), are present in the raw manure fed to the digester and do not undergo conversion. The concentrations of these constituents are different for different manures: their quantities are dependent on the feed or range grass ingested by the cattle; ultimately, they are dependent on the soils in which the feed is grown. When digester effluent is discharged, inorganic salt loads which have accumulated in the digester also will be discharged, possibly affecting water or soil quality.[59/]

The EPA has documented water quality criteria applicable to water bodies and waters for irrigation.[56/] These criteria cite levels of pollutants that can exist in waters while not harming the environment. Disposal of waste sludge may affect pollutant levels in areas governed by these criteria. If digester wastewater is introduced directly into a stream, the waterway should have sufficient volume to dilute the pollutants to acceptable levels. For land application, digested sludge should not be used in one area for extended periods, since this may concen-

TABLE III-6*
EFFLUENT CHARACTERISTICS OF A BIOCONVERSION SYSTEM AT TWO OPERATING SITUATIONS
(mg/1)

EFFLUENT CONDITION FROM DIGESTER	SS (%)	COD (TOTAL)	COD (DISSOLVED)	Kj-N	NH_4-N (MEAN)	NO_2-N	NO_3-N
High Solids	5.80	35,300	6,230	4,170	3,000	Neg.	Neg.
Low Solids	4.80	28,250	5,000	3,300	2,300	Neg.	Neg.

*Information based on values given in Ref 58, which appear on page 446 of the reference.

trate salts and toxic metals in the soil. For example, the volume of sludge effluent used to irrigate 1 acre (0.4 hectares) may contain the equivalent of 10 acres (4 hectares) of collected waste and the salts it contains. Concern would arise only if digester effluent were continually applied to one area. For example, the following compounds -- if present in large quantities in digester effluent -- could cause problems if irrigation is thus applied:

- Boron - At concentrations of 1 mg/l, boron is toxic to a number of sensitive plants. In general, sensitive crops show toxicities at levels of 1 mg/l or less, semi-tolerant crops at 1 to 2 mg/l, and tolerant crops at 2 to 4 mg/l. At boron concentrations above 4 mg/l, irrigation water is unsatisfactory for most crops.

- Copper - Concentrations of 0.1 to 1.0 mg/l in nutrient solutions have been shown to be toxic to a large number of plants. Toxicity levels in nutrient solutions and limited data on soils suggest a maximum concentration of 0.2 mg/l for continuous use on all soils.

- Iron - Iron is so insoluble in aerated soils at all pH values in which plants grow well that it is not toxic. However, soluble iron salts in irrigation water contribute to soil acidification, and the precipitated iron increases the fixation of such essential elements as phosphorus and molybdenum.

If sludge drying ponds channel runoff to existing waterways, the volume flow of the waterway should be of a magnitude that allows proper dilution of pollutants; if not, treatment of the discharge would be needed. Partial treatment occurs in the evaporation pond itself. Some organic solids settle out with the undissolved solids of the digester effluent.* In addition, settling of solids reduces respective inorganic concentrations within the solution. However, dissolved salts and dissolved organics will remain in solution, posing impacts on water quality.

The design of a sludge drying lagoon also must take into account percolation of water through the soil matrix. Infiltration of wastewater from the lagoon may eventually reach groundwater. Soils must be able to "cleanse" this wastewater before it reaches the water table, or they must be impervious to its flow [see Section III-B-2(h)].

Water requirements represent another impact that should be considered. Water requirements for the three digester designs run from 120 (455 l) to 12,000 gallons (45,500 l) per day. The high figure is roughly equivalent to the flow from a fast running garden hose. The problems of such requirements are inevitably determined by the location of the facility, i.e., water abundant or water depleted areas. Recycling schemes would help mitigate such requirements if proven practical.

Finally, existing water quality may affect digester operation. For example, large salt loads in the water will affect the growth of the anaerobic bacteria. In addition, such concentrations may reach undesirable levels when combined with concentrations present in the waste. Usually, such problems will not be encountered when using native surface waters of farmland areas, as crops will not tolerate such concentrations. However, waters used from areas of significant salt loads may present some problems.

Inhibitory concentrations to digester operation of alkaline and alkaline-earth cations are given below:[60/]

- Sodium - 8,000 mg/l;
- Potassium - 12,000 mg/l;

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*Thus, reduced pollution associated with these compounds, i.e., BOD/COD.

- Calcium - 8,000 mg/l; and
- Magnesium - 3,000 mg/l.

(3) Effects on Air Quality

Air quality impacts associated with digester operation are chiefly those of odor, with some occupational exposure concerns involved. Gas production for the three digester designs will average 800 (10 cow), 8000 (100 cow), and 80,000 (1000 cow) cubic feet per day. Generally, the gas produced by a digester will have a composition of about 55 percent methane, 45 percent CO_2, and less than 1 percent each H_2S and NH_3. Emissions of concern are H_2S and NH_3.

If the gas produced is burned onsite, H_2S and NH_3 will be oxidized to water, nitrogen oxides, and sulfur oxides. Bioconversion units generating large amounts of gas (approaching one million cu. ft. per day) may employ scrubbers to remove these materials prior to combustion or introduction of the product gas into standard gas pipelines. In this case, CO_2 removal would also be required. H_2S and NH_3 also will be present, to some extent, in the wastewater effluent from the digester. In a sludge drying pond exposed to air, these constituents will be oxidized. However, some odor problems may result from H_2S (and possibly NH_3) in the wastewater.

Biomass does not contain a large amount of sulfur, although concentrations of 0.37 percent (by weight) have been measured in cow manure (see Table II-4). Sulfides produced in anaerobic treatment may exist in a soluble or insoluble form, depending upon the cations with which they become associated. The actual distribution of sulfides depends upon digester pH and the quantity of gas produced from the waste. At a manure sulfur content of 0.2 percent, a digester running at a pH of 7.2 could have a raw gas stream consisting of approximately 1900 ppm H_2S.* Exposures of such quantities from leakage of untreated product gas may pose an odor as well as an occupational concern. The maximum permissible exposure level to H_2S set by OSHA is 20 ppm. Physiological responses to various concentrations of hydrogen sulfide have been reported as follows:61/

- 10 ppm: Beginning eye irritation;
- 100 ppm: Coughing, eye irritation, loss of sense of smell after 2 to 15 minutes. Altered respiration, pain in the eyes, and drowsiness after 15 to 30 minutes, followed by throat irritation after 1 hour. Several hours' exposure results in gradual increases in severity of these symptoms, and death may occur within the next 48 hours;
- 500 to 700 ppm: Loss of consciousness; death possible in 30 minutes to one hour; and
- 1000 to 2000 ppm: Unconsciousness at once, early cessation of respiration, and death in a few minutes. Death may occur even if individual is removed to fresh air at once.

Exposure of such high concentrations H_2S would not occur during normal digester operation since the product gas - in the majority of cases - will be upgraded to remove contaminants before combustion. Processes for upgrading the gas include those methods such as the molecular sieve, which dehydrates and removes carbon dioxide and sulfur compounds from the product gas stream. Even in the rare cases in which untreated gas will be combusted onsite, H_2S emissions should not occur since combustion will oxidize organic sulfides to SO_2 (in these cases, resulting ambient SO_2 concentrations would then be of interest).

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* This is an estimate based on information given in Reference 60, assuming all incoming sulfur to the digester is soluble sulfides.

Cases in which H_2S concentrations from the digester gas would pose a concern are those in which accidental leaking occurs. In these instances, ambient air standards could be violated and a definite impact from odor would result. However, once vented into the open atmosphere, it is unlikely that a health and safety impact would occur (based on modeling efforts, maximum downwind concentrations of H_2S from venting of raw digester gas would be approximately 0.9 ppm).

Ammonia produced during anaerobic treatment is present either in the form of the ammonium ion (NH_4^+) or as dissolved ammonia gas. These two forms are in equilibrium with each other, the relative concentration of each depending upon the pH of the solution; at high pH levels (>7.2), the ammonia gas concentration increases. Because the ammonia gas is inhibitory to digester organisms at a much lower concentration than the ammonium ion, large quantities of NH_3 gas are self-limiting. At a nitrogen-ammonia concentration above 3000 mg/liter, the digester environment becomes unhealthy for the organisms.[60/]

The time-weighted OSHA standard for ammonia exposure (40-hr week) is 25 ppm. Control of this pollutant in the gas stream can be accomplished - as with H_2S removal - through scrubbing. However, concentrations of ammonia encountered in digester operation will seldom exceed the level of an irritant or odor source.

(4) Effects on Land Use

Land requirements for the three digester facilities are estimated to be:

- 0.05 acres (0.02 hectares) or less for the 10 cow digester;
- 0.1 acres (0.04 hectares) or less for the 100 cow digester; and
- 0.1 to 0.2 acres (0.04 to 0.08 hectares) for the 1000 cow digester.

Additional requirements for 20-foot (6m) deep sludge drying beds are:

- less than a tenth of an acre (0.04 hectares) per year for the 10 cow operation;
- approximately 0.14 acres (0.06 hectares) per year for the 100 cow operation; and
- approximately 1.3 acres (0.53 hectares) per year for the 1000 cow operation.

(5) Effects on Solid Waste

Dewatered sludge solids from the digester may be disposed according to the criteria outlined below (i.e., disced into soil, etc.). In each case, concern should be directed to the eventual fate of the digester-waste pollutants; for example, would land application of solids to a particular area allow run-off of these pollutants to occur into drinking water supplies?

Dewatered sludge solids from the digester may be disposed of according to the criteria outlined below (i.e., disced into soil, etc.). In each case, concern should be directed to the associated with digester sludge wastewaters may therefore be amplified in dewatered solids.

b. Present Waste Management Practices[62/63]

Present waste management practices of anaerobic digestion sludge from municipal and industrial digesters have established a wide range of options, compatible to applications of biomass conversion. In particular, those practices dealing with land applications of digester effluent offer attractive alternatives of disposal for bioconversion facilities located in rural areas (i.e., feedlot and dairy farm digesters). Total effluent as well as dewatered sludge may be land-applied. In addition, there are other disposal methods available where such application is not desirable. A summary of those practices considered most relevant to bioconversion is presented in the following sections.

(1) Irrigation

Land application of wastewater is an old practice - it was used by the Greeks in Athens and was begun in the United States over 100 years ago. Hundreds of communities throughout the nation currently use one form or another of land application, irrigation being the most widely used type, with over 300 U.S. communities practicing this approach according to the 1972 Municipal Wastewater Facilities inventory conducted by EPA.

Irrigation water may come from either effluent piped directly to the field or from a holding pond, where settling is allowed to occur. There are three basic methods of effluent irrigation: spray, ridge and furrow, and flood. Spray irrigation may be accomplished using a variety of systems from portable to solid-set sprinklers. A very common technique is direct disposal of liquid digested sludge to land by spraying from tank wagons having a capacity of 1000 gallons (3790 l). Ridge and furrow irrigation consists of applying water by gravity flow into furrows. Flood irrigation is accomplished by innundation of land with several inches of water. The type of system to use depends on the ability of the soil to be drained, the crops, and the climate.

The EPA has developed recommendations of pollutant concentrations for wastewaters applied by irrigation to both crop and grazing lands.[56/] These would be applicable to anaerobic digestion sludge disposal. It should be understood that the criteria established by EPA are generalized recommendations, and do not guarantee successful application to all soils. Toxicity levels in the soil are dependent upon many variables, including drainage, permeability, soil chemical composition, and wastewater composition. For successful irrigation, soils should be assayed for existing levels of toxic compounds.

> Soil is affected greatly by the application of wastewater, and in many cases the effects are beneficial. Soil fertility is increased by the addition of nutrients. Soil tilth and, in some cases, excess sodium conditions have been corrected.
>
> Soils used in irrigation have considerable organic and clay contents so that retention of phosphorus, fluoride, metals, nondegradable organics, bacteria, and viruses takes place to a great extent. Also, irrigation depends upon evaporation for removal of a considerable portion of the applied wastewater, and this process concentrates the constituents that remain in the water. As a consequence plant toxicity that is due to buildup of metals and TDS can develop. Phytotoxic concentrations of copper and zinc have apparently accumulated in the soil at two sewage farms in France, but it has taken over a century for them to develop. Phytotoxic levels of TDS can be remedied by leaching (adding excess irrigation water).
>
> The application of wastewater to crops is beneficial because of the natural fertilizers and nutrients in the liquid. Virtually all essential plant nutrients are found in wastewater.
>
> The nutrients derived from wastewater are nitrogen, phosphorus, potassium, lime, trace elements, and humus. Nitrates can be utilized by growing plants. By applying wastewater intermittently, nitrogen will be converted to the nitrate form and will be fully available to crops during the growing season.
>
> Calcium in the form of lime is an indirect fertilizer that neutralizes acidity and checks some plant diseases. Soils high in organic matter, such as muck and peat, are generally deficient in calcium as are clayey soils. Calcium in sewage exists in the form of carbonate, which is favorable to important soil organisms. Trace elements in wastewater are sulfur, magnesium, iron, iodine, sodium, boron, manganese, copper, and zinc. These elements can be helpful in plant development; however, in high concentrations, they can be toxic.

Toxic elements can be toxic either to the plants or to the animal that consumes the crop. Analysis of the soil and of the crop itself will give the levels of concentration of any toxic elements so that proper crops can be selected. Certain crops have a higher tolerance for toxic substances than others. An example is oats and flax with respect to nickel. Oats have a high tolerance at 100 mg/l, while flax has a low tolerance at 0.5 mg/l.

The uptake of a toxic substance, like lead, into the edible portions of the plant has been studied to determine soil concentrations necessary to create toxic conditions.

Bromegrass grown in soil with as high as 680 mg/l of lead had only 34.5 mg/l of lead in the leaves. This is well below the 150 mg/l level of toxicity to cattle and horses and caused no detrimental effects on the plants.

The plants will not be harmed by pathogenic organisms but animals that consume the plants could be harmed. Organisms can enter plants through bruises or cuts but generally they are not absorbed by the plants.[59/]

In addition to concerns for plant and grazer toxicity, the soil where wastewater irrigation is applied must be able to "recharge" the water before it reaches the native groundwater. Because the major portion of the wastewater applied infiltrates the surface and percolates through the soil matrix, nutrients that are not used by plants or fixed in the soil can leach down to the groundwater and cause contamination.

Nitrates are a particular concern as they are highly mobile. Phosphorus may also leach to the groundwater if it is not fixed or used by the crop, but this occurrence is rare in irrigation practice.

Generally, toxic organic compounds are rendered nontoxic by the bacteria present in the soil. Problems are encountered sometimes with open soils which allow water to carry the organics through too fast.

Air quality may be a problem with spray irrigation which creates aerosols subject to wind travel. Some irrigation sites have 50 to 200 foot (15 to 61 m) buffer zones around the irrigation area so that the travel of the airborne droplets is limited within the site.

Odors may also be troublesome; elimination is best realized by examining operating procedures which may include overloading or irrigation of a sealed surface.62/

(2) Sludge Drying Beds 63/

Lagooning is the most popular liquid sludge disposal technique at industrial treatment plants. Lagoons may be natural depressions in the ground or artificially constructed.

Sludge drying beds are those lagoons where sludge is allowed to evaporate, leaving solids which are periodically removed with subsequent refilling of the lagoon. Percolation of water through the soil also takes place and this is desirable unless contamination of groundwater is a threat. Many States require that the lagoon bottom must be at least 18 inches above the maximum water table in order to prevent contamination.

In designing a drying lagoon, discharge systems that limit sludge travel to 200 feet (61 m) are recommended as well as diked embankments with a 1:2 slope on the exterior side and 1:3 on the interior to prevent erosion. Most procedures call for discharging sludge from the digester to the lagoon at regular time intervals as determined by the solids accumulation in the digester. For example, a three-year cycle would employ a one-year loading, an eighteen-month drying period, and a resting period of six months.

To aid in satisfactory operation, evaporation is desirable and, clearly, climatic conditions that favor evaporation are beneficial. Sludge dried in a bed, however, may not be dried to less than 70 percent moisture, but at this point it can be removed by mechanical excavation. "Dried" sludge removed from the lagoons may be either landfilled, used as a soil conditioner, or composted.

Dewatered sludge cake may serve as a soil conditioner, but it lacks many of the nutrients that were present in the liquid which was lost in the dewatering process; at least half the nitrogen content has been lost with the liquid portion. Care should be exercised in avoiding toxic soil thresholds as inorganics are concentrated in the sludge cake; however, this may not be a problem unless certain industrial sludges are used.

Dewatered sludge properly stabilized by digestion can be disposed into a sanitary landfill. The sludge cake can be added to municipal refuse or, if it has a solids content of about 30 percent or higher, it can be disposed in a landfill without any other refuse. Dumping or landfilling may be satisfactory if:[63/]

- sufficient land area is available;
- the dump site is sufficiently far from populated areas that odor and appearance are not a nuisance and the pathogen content is not a hazard;
- runoff to watercourses is controlled; and
- percolation of leachate to groundwater is controlled.

Odors can be reduced by not overloading and/or soil cover.

Drying lagoons are usually constructed with a capacity anywhere from 0.4 to 0.5 cu. ft. per pounds solids per year

(0.025 to 0.031 m^3/Kg/yr). Environmental problems associated directly with lagoons are those of odor and pest populations. If completely digested, lagoons may present odor problems which may be countered by disinfectant addition. Lagoons may also support insect populations, such as mosquitos, and proper elimination steps will have to be taken in these cases.

Climate plays an important part in successful drying bed operations, drying being aided by arid conditions. Large rainfall areas should be avoided as such conditions can present problems in lagoon operation.

Finally, proper precautions must be taken to avoid native groundwater contamination by percolation of the digester liquid through the soil. If soils are very porous and/or native groundwater is of excellent quality, problems may result. In general, precautions must be taken in relation to climate, subsoil permeability, sludge loading rates, and sludge characteristics.

(3) Other Disposal Methods

- Mechanical Dewatering - The primary objective of any dewatering operation is to reduce the sludge moisture content to a degree which allows ultimate disposal by incineration, landfilling, heat drying, etc. In a bioconversion system, mechanical dewatering may primarily be employed for producing a dried cake which can be tested for its feed value. Mechanical dewatering may include the following:
  - Vacuum Filtration;
  - Pressure Filtration;
  - Centrifugation; and
  - Screening.

Of these processes, vacuum filtration and centrifugation are the most applicable for successful dewatering to a solid.

Dewatering by vacuum filtration is applicable to all types of sewage sludge. Usually chemical conditioning is a necessary step prior to dewatering, the most popular chemical materials being ferric chloride, lime, and cationic polyelectrolytes. Cake moisture from vacuum filtration varies from 55 to 85 percent by weight depending on the type of sludge handled and the filter operating conditions. Normally, filtration of digested sludge requires a "tight" filtration medium because of the minute particles present in the effluent.

Centrifuges are becoming competitive with filters in wastewater management practices but will probably not replace filters because they capture fewer solids and, in general, are less efficient for dewatering certain difficult biological and industrial waste sludges. However, centrifugation has some inherent advantages over vacuum filtration in that it is simple, compact, totally enclosed, flexible, normally used without chemical aids, and the costs are moderate.

- Discharge into public treatment works - This form of disposal may involve direct piping into public treatment works or portable transport via tanker trucks to public treatment works.

If the dewatered sludge cake is to be used as a feed ingredient, as proposed in some bioconversion schemes, precautions will have to be taken such as heating to destroy toxic organisms. This area will have to be investigated in the future to determine proper pollution control of the sludge cake, if this application is shown to be viable.

Discharge of digester effluent from bioconversion facilities must meet recommended pretreatment guidelines before introduction to the public works wastewater system. Anaerobic digester effluent from a cattle manure feedstock will probably meet these requirements without additional treatment, but this is of course dependent on the composition of the manure.

3. Environmental Impacts of Combustion

The impacts of burning biomass for heat energy, particularly wood combustion, are similar to those currently encountered in combustion of fossil fuels. However, certain characteristics of biomass help mitigate these impacts. These are the low sulfur and ash contents of wood, which result in low sulfur dioxide emissions and small land requirements for ash disposal. (In addition, biomass ash may be applied to land for its beneficial mineral supplementation.)

Boiler combustion of wood is a well developed technology, having served the pulp and paper industries since their inception. Currently there are a number of boiler designs, as well as emission control systems that are specifically suited to wood combustion. The areas of additional environmental concern stemming from this biomass conversion process involve the logistics of transporting the wood fuel from the forest to points of use. For large facilities approaching those of present electric utility capacities, massive amounts of wood fuel are needed, possibly causing impacts from the requirements of transportation and roadways used in handling. Until such designs are elaborated, however, these impacts cannot be accurately determined.

a. Effects on Air Quality

(1) Effects of Construction

The construction of a wood burning boiler, typically a flat or traveling grate design, will cause no air quality problems beyond those of the construction of any other type of boiler or industrial installation. Construction of such an installation will involve the clearing of vegetation, and consequent air problems will be caused by fugitive dust emissions from unprotected soil (cf, Air Quality Section in "Thermochemical Impacts").

Normally less than an acre of land is needed for the construction of a wood boiler, the construction lasting some six months to a year.

(2) Effects of Operation

The air emissions produced during biomass combustion are similar in nature (not quantity) to those produced from combustion of fossil fuels. The major pollutant of concern from wood boilers is particulate matter, although other pollutants, particularly carbon monoxide, may be emitted in significant amounts under poor operating conditions (this is also true for other fossil-fuel fired boilers). The emissions depend on a number of variables including (1) the composition of the waste fuel burned, (2) the degree of fly-ash reinjection employed, and (3) furnace design and operating conditions.

The composition of wood waste depends largely on the industry from whence it originates. Pulping operations, for instance, produce great quantities of bark that may contain more than 70 percent moisture (by weight) as well as high levels of sand and other noncombustibles. Because of this, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are well controlled. On the other hand, some operations such as furniture manufacture, produce a clean, dry (5 to 50 percent moisture) wood waste that results in relatively few particulate emissions when properly burned. Still other operations, such as sawmills, burn a variable mixture of bark and wood waste that results in particulate emissions somewhere in between these two extremes.

Fly ash reinjection, which is commonly used in many larger boilers to improve fuel-use efficiency, has a considerable effect on particulate emissions. Because a fraction of the collected fly ash is reinjected into the boiler, the dust loading from the furnace, and consequently from the collection device, increases significantly per ton of wood waste burned. It is reported that full reinjection can cause a 10-fold increase in the dust loadings of some systems, although increases of 1.2 to 2 times are more typical for boilers employing 50 to 100 percent reinjection. A major factor affecting this dust loading increase is the extent to which the sand and other noncombustibles can be successfully separated from the fly ash before reinjection to the furnace.

Particulate stack emissions from wood-fired boilers mostly depend on furnace design, operating conditions, and particulate controls. Because of the high moisture content of wood, a large refractory surface and sufficient air should be provided to allow for complete combustion of the wood. Incomplete combustion results in increased particulate emissions, as well as increased carbon monoxide and hydrocarbon emissions. For mechanical control of particulates, cyclone designs are the most commonly used. These can achieve a particulate control efficiency of up to 90 percent.

Table III-7 presents a comparison of emission factors for wood burning boilers compared to utility boiler emissions of fuel oil and coal. For wood boilers, two particulate factors are shown: the first represents uncontrolled emissions; the value in parenthesis reflects emissions after particulate controls. All other factors represent uncontrolled conditions.

Trace elements are contained in fossil fuels and in wood in minute concentrations. These elements, in sufficient quantities, can cause adverse environmental and health effects. During com-

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TABLE III-7

UNCONTROLLED EMISSION FACTORS FOR WOOD COMBUSTION AS COMPARED TO UNCONTROLLED COAL AND FUEL OIL COMBUSTION

(in lb/MMBtu [Kg/10^9 cal])

EMISSIONS

POLLUTANT	WOOD		OIL		COAL	
Particulates	3.0(0.3)	[5.4(0.5)][a]	0.055	[0.099]	6.8 (0.10)	[12.2(0.18)][b]
SO_2	0.15	[0.27]	2.2	[3.9]	1.52	[2.74]
CO	0.2-6.0	[0.3-10.8]	0.020	[0.361]	0.040	[0.722]
Hydrocarbons	0.2-7.0	[0.3-12.6]	0.014	[0.253]	0.012	[0.022]
NO_x	1	[1.8]	0.724	[1.306]	0.720	[1.298]

FUEL CHARACTERISTICS

	WOOD[c]	OIL	COAL
Heating Value	5000 Btu/lb (2770 Kcal/Kg)	146,000 Btu/gal (641 Kcal/1)	12,500 Btu/lb (6,930 Kcal/Kg)
Ash Content (%)	1	0.7	10
Sulfur Content (%)	0.1	2.0	1

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a/ Value in parenthesis represents particulate controls of 90% efficiency.

b/ Value in parenthesis is EPA New Source Performance Standard, achievable with control efficiency of 98.5%.

c/ 50% moisture content.

Source: Compilation of Air Pollution Emission Factors, Ref. 54.

bustion, these small quantities of toxic elements can vaporize or form particulates which are then entrained in the exhaust. Trace elements from utility boilers have not been observed to cause adverse environmental effects, although their long-term or overall impact has not been well defined. In general, wood combustion does not present a problem in this area. Table III-8 lists concentrations and emission factors of trace elements in coal and oil fuels and compares them with trace metal concentrations in biomass. From the table, it can be seen that wood ash compared to coal ash contains far less quantities of trace elements, with the exception of cadmium.

b. Effects on Water Quality

(1) Effects of Construction

The construction of a wood burning boiler causes no water quality problems beyond the increase of sediment wash, resulting from the clearing of vegetation. Compared to grass-covered land, the uncontrolled sediment load wash to surface water is increased 20-fold per acre of uncovered soil; the increase jumps to 100-fold for uncovered soil when compared to forested land. The sediment load from uncontrolled, uncleared land is typically 5 to 50 tons per acre per year (11 to 110 metric tons/hectare/year); however, depending on rainfall characteristics, topography, and soil types, the load amount can vary well beyond this range. Control techniques such as ditching and temporary cover can reduce sediment loads to natural levels.[44/]

Normally, less than an acre (0.4 hectare) of land is needed for the construction of wood boilers, the construction period lasting from six months to a year. No significant groundwater impacts are anticipated during this construction.

(2) Effects of Operation

Generally, boiler systems have many water dependent subsystems, including pretreatment processes for boiler water,

TABLE III-8
TYPICAL LEVELS OF TRACE ELEMENTS IN FOSSIL FUELS AND BIOMASS

	Coal		Oil		Biomass
Element	Concentration[a/] (ppm)	Emission Factor (g/10⁶ Btu)[b/]	Concentration[a/] (ppm)	Emission Factor (g/10⁶ Btu)[c/]	Concentration[d/] (ppm)
Antimony	5	0.20	0.024	0.0059	0.06
Arsenic	32	1.3	0.08	0.002	0.2
Barium	500	20.2	0.11	0.003	14
Beryllium	2.44	0.099			0.1
Boron	61	2.47			15
Cadmium	0.03	0.001			0.64
Chlorine	160	6.48			2000
Chromium	15.4	0.624			0.23
Cobalt	4.8	0.194			0.48
Copper	13.5	0.547			14
Fluorine	82	3.32			0.5
Lead	9.5	0.38			2.7
Manganese	50	2.02	0.04	0.001	630
Mercury	0.15	0.0061			0.15
Nickel	14.8	0.599	16	0.39	2.7
Selenium	2.2	0.089			0.2
Tin	0.9	0.036	0.8	0.02	0.3
Titanium	385	15.6			1
Vanadium	26.4	1.07	9	0.22	1.6
Zinc	12	0.49			160

a/ Source: Potential Pollutants in Fossil Fuels.

b/ Based on heating value of 11,200 Btu/lb for coal as burned.

c/ Based on heating value of 18,400 Btu/lb for residual oil as burned.

d/ Source: Trace Elements in Biochemistry, Ref. 55.

Source: Hazardous Emission Characteristics of Utility Boilers, Ref. 64.

water carrying cooling pipes, and blowdown (cleaning) operations. Internal powerplant-related activities such as cooling, boiler feed, water pretreatment, steam blowdown, and boiler cleaning are relatively independent of the fuel source used to fire the unit. Miscellaneous support activites such as sanitary systems, laboratory and sampling, and intake screen backwashing likewise are independent of fuel types. Consequently, the environmental impact of these activities in wood-fired boilers will be similar to operations internal to coal, gas, and oil-fired units. In this regard, coal serves as the most appropriate analog, as coal-fired boilers are capable of being fired with wood, with little alteration.

Remaining water dependent subsystems, however, are affected according to fuel type. Two sources of fuel-dependent pollution can be expected from wood or biomass-fed units: the storage of fuel and the disposal of ash.

The storage requirements for wood residues are minimal since, at a plantation site particularly, production and utilization of wood residues coincide. Thus, the storage of wood residues need only be sufficient to handle collection and production surges. It is estimated that storage capacity for less than a week is adequate; consequently, covered storage piles (protected from rainfall) should not cause any appreciable water impacts.

However, if other biomass feedstocks are used alone and/or in combination with wood, some problems may result if they contain a high moisture content. Wood is resistant to the anaerobic decay process in comparison to crop residues, which may generate anaerobic decay pollutants if proper management is not employed. Leachates that may affect water quality under anaerobic decay conditions are similar to those encountered in anaerobic digestion (i.e., BOD, COD, NH_3, H_2S), though of a lesser degree. It is expected, however, that wet crop residues are the least likely candidate for direct burning.

The other major concern is that of ash disposal, which is a potential source of surface and groundwater pollution. Typically, wood ash contents are less than one percent. Wood containing 1.5 percent ash will generate approximately 3 pounds (ash) per million Btu (5.4 Kg/10^9 cal). Other fuels produce ash in the following ratios: 11 pounds per million Btu (20 Kg/10^9 cal) for coal and 0.1 pounds per million Btu (0.2 Kg/10^9 cal) for oil.

If ash is handled by a wet removal process, difficulties arise in its settling, creating floating and suspended solids. Conventional sedimentation and skimming treatments can easily reduce the discharged floating and suspended solids concentrations from wood ash to levels established pursuant to Public Law 92-500, as applied to coal-fired boilers.

Dry ash handling systems can eliminate any direct impacts on water quality. The leachates that can evolve from wood and their resulting effects on the environment have not been documented; however, wood ash residue has much lower acid and heavy metal concentrations than those from leachates of coal ash (see Table III-8).

c. Effects on Land Use

(1) Effects of Construction

In a survey of steam-electric power plants, the acreage needed for boiler installation requires approximately 0.1

acre per MW (0.04 hectare/MW) of rated boiler capacity. Thus, for wood-fired boilers up to 10 MW in rated capacity, less than one acre (0.4 hectare) of land need be disrupted for the construction. The area for storage of materials and equipment is expected to be available at the industrial site on which these boilers are built, and no additional land requirements should be necessary.

(2) Effects of Operation

Operation of a wood burning utility would affect land use in two ways: (1) acreage required for ash disposal, and (2) support acreage required for fuel production. Regarding the former, ash produced at a rate of 3 lbs/MMBtu (5.4 Kg/10^9 cal) will yield 92 tons (83 metric tons) of ash per year per MW of capacity, at 70 percent utilization. The land required for disposal would be less than 0.2 acres per MW (0.08 hectares/MW) over a twenty-year period, assuming a 20-foot (3 m) deep ash pit and an ash density of 50 pounds per cubic foot (800 Kg/m^3).

Land requirements for fuel production necessary to support a wood burning utility have varied estimates. Biomass yield is the determining factor. For electric rated utilities, land area estimates have run from 0.4 square miles (1.0 Km^2) to 2 square miles (5 Km^2) per MW.[65/]

Even small capacity utilities require substantial land resources. For example, an energy plantation is designed around the needs of a 100-MW facility which runs at 50 percent capacity throughout the year. Trees are grown on a 5-year rotation schedule and sustain a yield of 9.5 dry tons per acre-year (21 metric tons/hectare/year). If a value of 8500 Btu/lb (4710 Kcal/Kg) for wood is assumed, the following values result:*

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* Based on EEA calculations. See technology section on terrestrial biomass growth for examples of tree species and yields. See technology section on combustion for heat content of wood.

- 47.5 dry tons per acre (106 metric tons/hectare) are harvested on a 5-year rotation, yielding 8.1 x 10^8 Btu per acre (5.0 x 10^8 Kcal/hectare);
- the utility has an efficiency of 12,000 Btu (3000 Kcal) per kilowatt hour; it requires an annual heat input of 5.26 x 10^{12} Btu (1.33 x 10^{12} Kcal);
- 5.26 x 10^{12} Btu (1.33 x 10^{12} Kcal) are supplied by harvesting 6.51 x 10^3 acres (2.63 x 10^3 hectares) per year or 10.2 square miles (26.4 Km^2) ; and
- based on a 5-year station schedule, total plantation area is 50.8 square miles (131.6 Km^2), or 32,520 acres (13,160 hectares).

Regardless of yield assumptions or facility size, a major impact of a fuel plantation is its utilization of immense tracts of land.

d. Effects on Solid Waste

(1) Effects of Construction

In erecting a wood burning boiler, the sole source of solid waste is the vegetation cleared from approximately one acre of land. As in biomass thermochemical conversion facilities, the cleared vegetation may be disposed of by utilizing it as biomass fed to the unit. Thus, the amount of vegetation persisting as a solid waste problem is expected to be less than that encountered from construction of industrial facilities of a similar size.

(2) Effects of Operation

As previously discussed, ash from wood combustion will total some three pounds per million Btu (5.4 Kg/10^9 cal), resulting in an accumulation of 92 tons (83 metric tons/MW) per year. Disposal of this waste is estimated to require less than 0.2 acres per MW (0.08 hectares/MW) in rated capacity for 20-year accumulations, assuming a 10-foot (3 m) deep ash pit.

e. Effects on Ecosystems

Internal power plant activities (blowdown, boiler tubes cleaning) affecting water quality will impact aquatic ecosystems much as those of coal- or oil-fired power plants do. Such impacts usually result in short-term high concentrations of acids and metals in the water, which commonly do not cause adverse impacts. Furthermore, if this discharge does not reach waterways, such impacts will not occur.

Disposal of ash can also affect ecosystems if salt loads of the ash reach food chains. However, because of the low rate of ash generation in wood combustion and its low concentrations of trace elements, this impact is not likely to occur on an observable level.

By far, the greatest ecosystem impacts will arise from the use of land in fuel production. These impacts have been previously discussed.

f. Effects on Esthetics/Noise

The principal noise sources associated with a wood-fueled facility will be heavy equipment traffic and bulldozers used in the handling of wood fuel. The chipping, or "hogging," of the fuel for boiler injection will also generate noise.

For workers at a power plant, the National Institute of Occupational Safety and Health (NIOSH) of HEW recommends that 8-hour daily exposures not exceed 90 dBA. Enforcement of these levels is carried out by the Occupational Safety and Health Administration. Such levels can be easily attained through use of any standard control options: equipment modification, limiting exposure time, etc.

4. Environmental Impacts of Direct Hydrogen Production

Environmental impacts pertaining to hydrogen production via alteration of the photosynthetic process in blue-green algae can be only broadly addressed, as the technology of this conversion process is at a very early stage.

The potential impacts are twofold: odors from decaying biomass due to process upset, and local imbalances of carbon dioxide and oxygen. The latter requires large-scale implementation and results from the production of hydrogen, occurring at the expense of normal photosynthetic conversion of CO_2 to O_2.

Potential water impacts may arise from the use of nutrient laden waters to support algae growth. Wastewater may be appropriate for this use, and large surface ponds containing algae and wastewaters may affect water quality from overflow or infiltration of the soil nature. However, the use of such waters may represent a desirable disposal method, with apparent benefits.

Thermal effects could also arise if large areas of water are used to support algae growth, thereby reducing the amount of solar radiation reflected off surface waters. These effects may be distributed between air and water affecting climate and water ecosystems. However, such impacts are remote. For the most part, more information is required before any environmental impacts can be determined on any reasonable scale.

C. Social/Institutional Impacts of Biomass as An Energy Source

Social and institutional impacts of biomass energy use primarily arise from biomass production, rather than biomass conversion. For biomass applications employing terrestrial vegetation, social/institutional impacts stem largely from the land areas required and the agricultural procedures employed. Consequently, land use impacts (including decisions on using Federal lands) and agricultural policies and regulations would be the major focus of institutional impacts from this technology.

Terrestrial biomass production also will result in competition with food and fiber markets for available resources, i.e., land, fertilizers, equipment, and water. Institutional regulations would be required to address conflicts during fiber shortages, and especially during possible food shortfalls. These regulations would prioritize needs in relation to food, fiber, or energy when conflicts in these markets occur from shortages.

Cultivation of aquatic plants for biomass will create additional social and institutional impacts as the methods used must be interfaced with existing water use and water quality regulations. Mariculture operations in particular may require development of new administrative and regulatory structures. Similarly, the possible interference of marine farms with fishing rights must be considered, and establishment of appropriate governmental jurisdiction (Federal, State, or International) would eventually be required.

SECTION IV

NEPA DOCUMENT WORK PLAN AND ENVIRONMENTAL RESEARCH PROJECTS

A. Introduction

The purpose of this section is to lay out a preliminary draft work plan for environmental analysis of the biomass production and conversion technologies being developed by the Energy Research and Development Administration (ERDA). It addresses the preparation of Environmental Development Plans, Environmental Impact Assessments, and Environmental Impact Statements, as well as the conduct of basic and applied research supportive of developing a better understanding of the environmental consequences of the "Fuels From Biomass" program.

The work scheduled in this report should not be construed as official plans of either the Division of Solar Energy or of ERDA as a whole. The work shown is that identified by the contractor. Many of the projects identified and outlined in Section D can be carried out outside of ERDA and can be handled in a variety of ways. The scheduled work does not take into account breakthroughs or findings which may allow for significant reductions in effort or expansions, and it may not reflect specific work already underway in the public or private sectors.

B. Description of NEPA Documents

1. Background

The National Environmental Policy Act of 1969 (NEPA), implemented by Executive Order on March 5, 1970, and the guidelines of the Council on Environmental Quality of August 1, 1973, require that all agencies of the Federal government prepare detailed environmental statements on major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the Federal agency decision-making process, at the earliest possible point, an appropriate and careful consideration of all environmental aspects of a proposed action in order that adverse environmental effects may be avoided or minimized.

In carrying out this mandate, each agency of the government has set out a policy and procedures for implementing these requirements. ERDA currently operates under official guidelines originally established by and for the now defunct Atomic Energy Commission. In an effort to update and reorient the guidelines to ERDA's needs, alternative guidelines are now being prepared within ERDA.

Although the proposed revisions have yet to be finalized or adopted because the proposed changes are so extensive and this document is to serve as an input to a future agency planning effort, for purposes of this analysis the most recent proposed revision (November 1, 1976) has been used to represent the future official guidelines. The discussion of NEPA report requirements and the recommended work schedule is predicated on the guidance provided in the November 1 draft revision.

The backbone of ERDA's NEPA compliance program is the preparation and review (by the agency and the public) of documents addressing the environmental aspects of programs and projects of the agency. Three types of documents are particularly important: Environmental Development Plans (EDP's), Environmental Impact Assessments (EIA's), and Environmental Impact Statements (EIS's). Each is described below.

2. Environmental Development Plans

An Environmental Development Plan (EDP) is the basic ERDA management document for the planning, budgeting, managing, and reviewing of the broad environmental implications of each energy technology alternative for each major ERDA research, development, and demonstration and commercialization program. The EDP is designed to identify environmental issues, problems, and concerns as early as possible during the program's development, to analyze the available data and assess the current state of knowledge related to each issue, problem, and concern, to set forth strategies to resolve these, to set forth the processes by which the public is involved in identification and resolution of these issues, problems, and concerns, and to designate significant milestones for resolution of these issues, problems, and concerns. The timing of the EDP's milestones reflects the sequencing of the technology development. EDP's, once completed, are made available to the public.

3. Environmental Impact Assessments

An Environmental Impact Assessment (EIA) is a written report, prepared by an assistant administrator or an ERDA program office, which evaluates the environmental impacts of proposed ERDA actions to assure that environmental values are considered at the earliest meaningful point in the decision-making process, and which, based upon the evaluation, determines whether or not an environmental impact statement should be prepared. The EIA is intended to be a brief, factual, and objective document describing the proposed action, the environment which may be impacted, the potential environmental impacts during construction, operation, and site restoration, potential conflicts with Federal, State, regional, or local plans, and the environmental implications of alternatives.

4. Environmental Impact Statements

An Environmental Impact Statement (EIS) is a document prepared at the earliest meaningful point in the decision-making process, which analyzes the anticipated environmental impacts of proposed ERDA actions and of reasonably available alternatives and which reflects responsible public and governmental views and concerns.

An EIS is prepared in response to plans in the program's EDP or after the review of an EIA which identifies potentially significant impacts. The EIS goes through a specific preparation process involving agency and public review.

The EIS goes through four steps during its preparation. The preliminary draft is reviewed within ERDA, the draft is distributed to the public for review and comment, the preliminary final incorporating comments submitted to ERDA in response to the draft is reviewed within ERDA, and the final EIS is issued reflecting the agency's final review and deliberations. This final EIS is then officially filed with the Council on Environmental Quality and distributed to the public. Except in special cases, no ERDA action subject to EIS preparation can be taken sooner than 30 days after the final EIS has been issued.

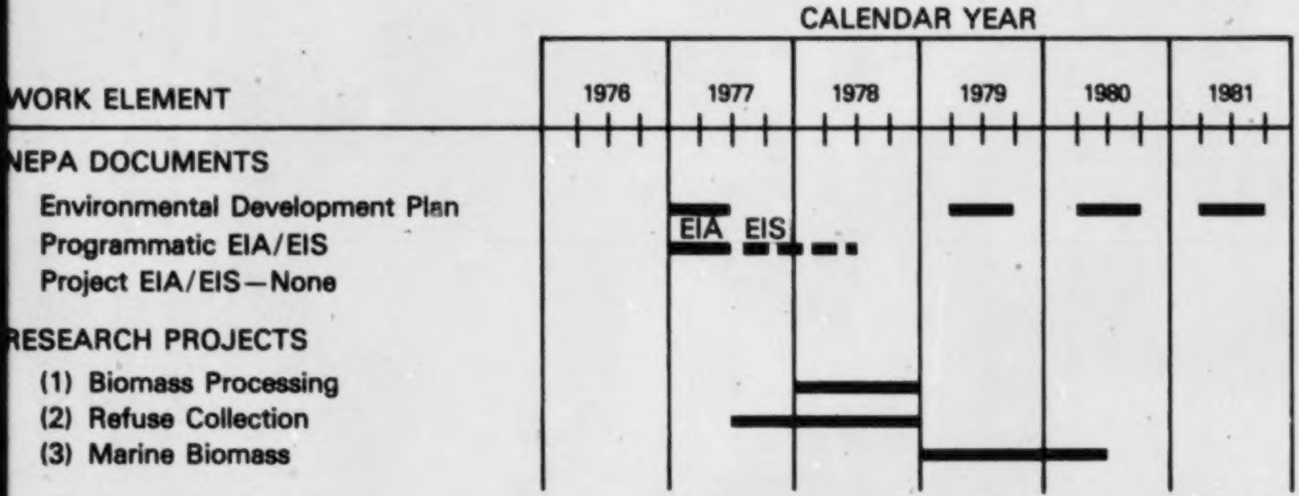
An EIS can be prepared covering programs, projects, or the use of ERDA facilities. In each case the document must reflect the utilization of a systematic interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts.

Contents of the report cover a description of the proposed action and alternatives, a description of the existing environment, an analysis of environmental impacts of the proposed action and its alternatives, and a specific review of the unavoidable adverse effects, resource use, land use implications, and the environmental tradeoffs represented by the proposed action and the alternatives.

C. NEPA Document Work Plan

Figure IV-1 presents an environmental work schedule for various biomass projects. Also included is a schedule for the various research projects which are proposed below.

FIGURE IV-1
FUELS FROM BIOMASS RESIDUE (EA0402) ENVIRONMENTAL WORK SCHEDULE



D. Research and Development Projects

Through the preparation of EEA's (Energy and Environmental Analysis) environmental survey of the ERDA "Fuels From Biomass" program, a wide range of environmental issues was identified which could not be analyzed adequately within the context of this study due to the complexity of the problem, the general lack of necessary research data, and the level of effort and schedule of the EEA study. This section identifies five specific follow-up research projects which the EEA staff felt were critical to the understanding of the environmental consequences of large-scale commercial application of biomass and which are not likely to be specifically or adequately addressed solely in the preparation of NEPA documents. Many other research projects were identified during EEA's study. This list represents a condensation and trimming down of draft lists to those projects which are felt to be of greatest importance to the advancement of biomass use and the associated decision-making process within the Federal government.

E. Biomass

1. Biomass Processing Characterization of Residuals

- The pyrolysis, hydrogenation, and gasification of biomass can produce significant quantities of air, water, and solid waste residuals of a potentially harmful nature. This study would utilize the vast body of information currently available on the application of similar methods to coal and oil shale to determine the types and quantities of these residuals and how they might be treated or avoided through process design modifications.

2. Plant Refuse Collection Net Environmental Impact Case Studies

- Identify farming operations where readily accessible crop residue of sufficient quantity could support a commercially viable biomass operation.

- For each location, document current residue handling practices and develop an operating scenario for biomass collection and use at the site.

3. Marine Biomass Impact on the Local Energy and Water Balances

- Analyze the magnitude and type of climatological effects one might expect with large-scale increased photo-absorption at the surface of the ocean.

- In particular, examine the impact on surface water temperature, evaporation rates, and secondary impacts on cloud formation and precipitation rates. [This study could be funded in conjunction with similar work on Ocean Thermal Energy Conversion (OTEC).]

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